Royal Netherlands
Meteorological Institute
Ministry of Transport, Public Works and Water Management

A-Train Climate Observations of Trace Gases and Aerosols

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Pieternel Levelt

The Netherlands: *A Climate Sensitive Country*

Thermal radiation

Ozone layer

Solar radiation

Stratosphere

Stratosphere-Troposphere exchanges

Troposphere

Gas phase chemistry

O_3

Long-range transport

Deep convection

CO_2
NO_2
CO
VOC (HCHO)
CH_4
SO_2

Heterogeneous Chemistry

Aqueous phase chemistry

Aerosols

Boundary layer mixing

Scavenging processes

Megacities

Fossil fuel Emissions

Dry deposition

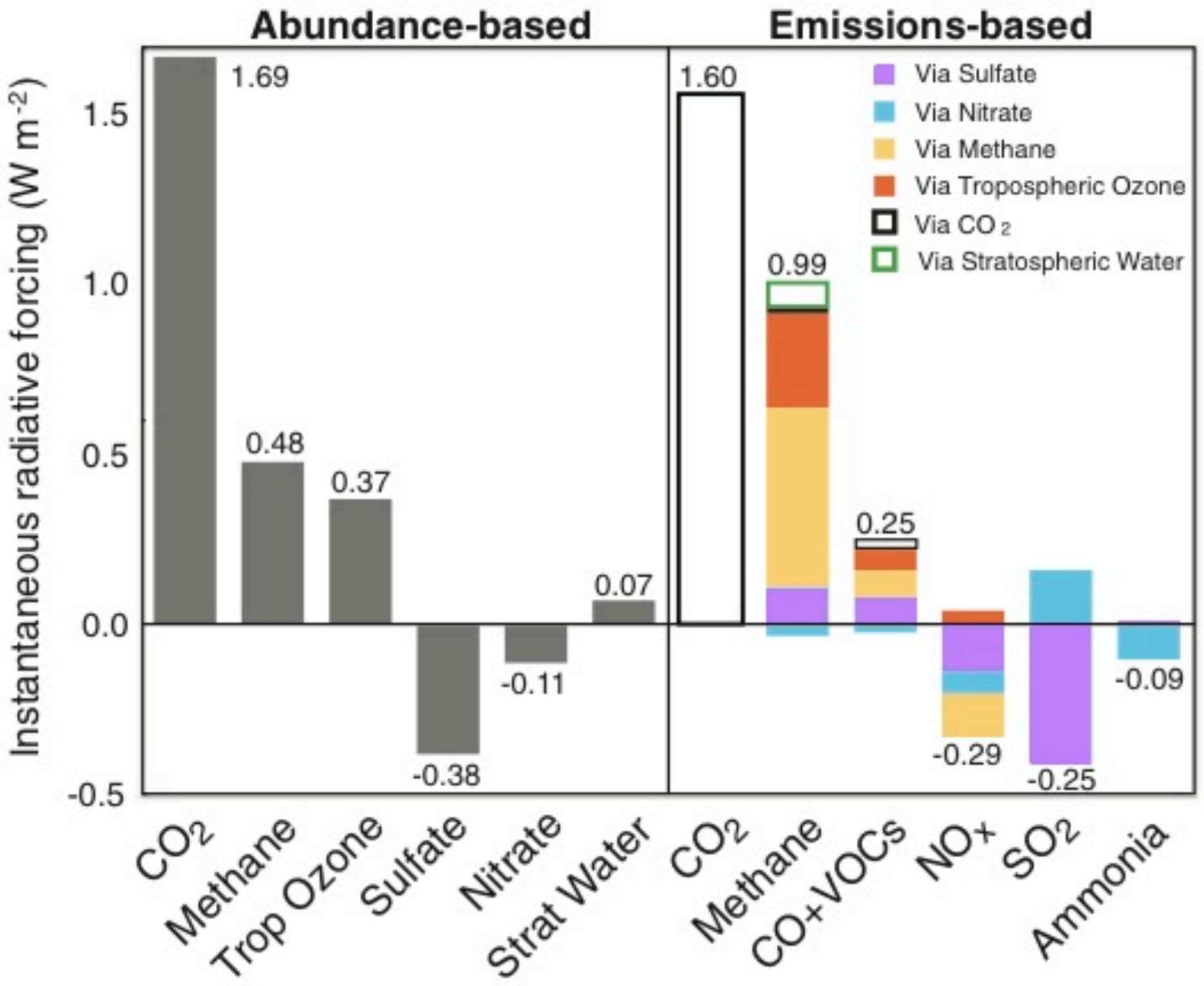
Air-sea exchanges

Biogenic emissions

Biomass burning emissions

Erosion

Courtesy:
D. Hauglustaine (CNRS, LSCE)

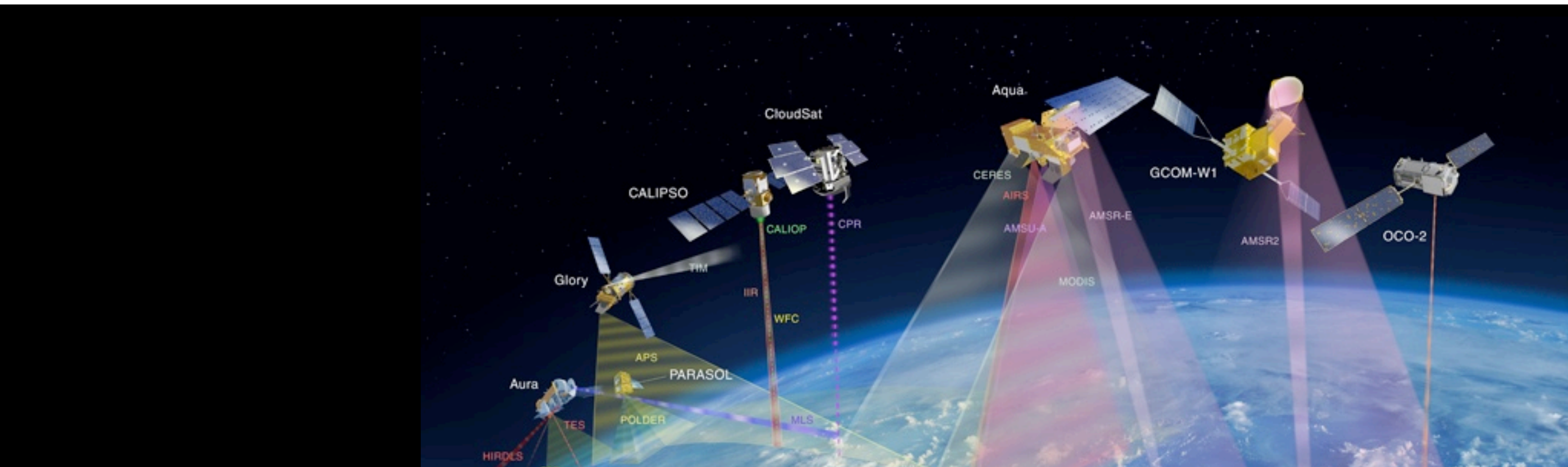


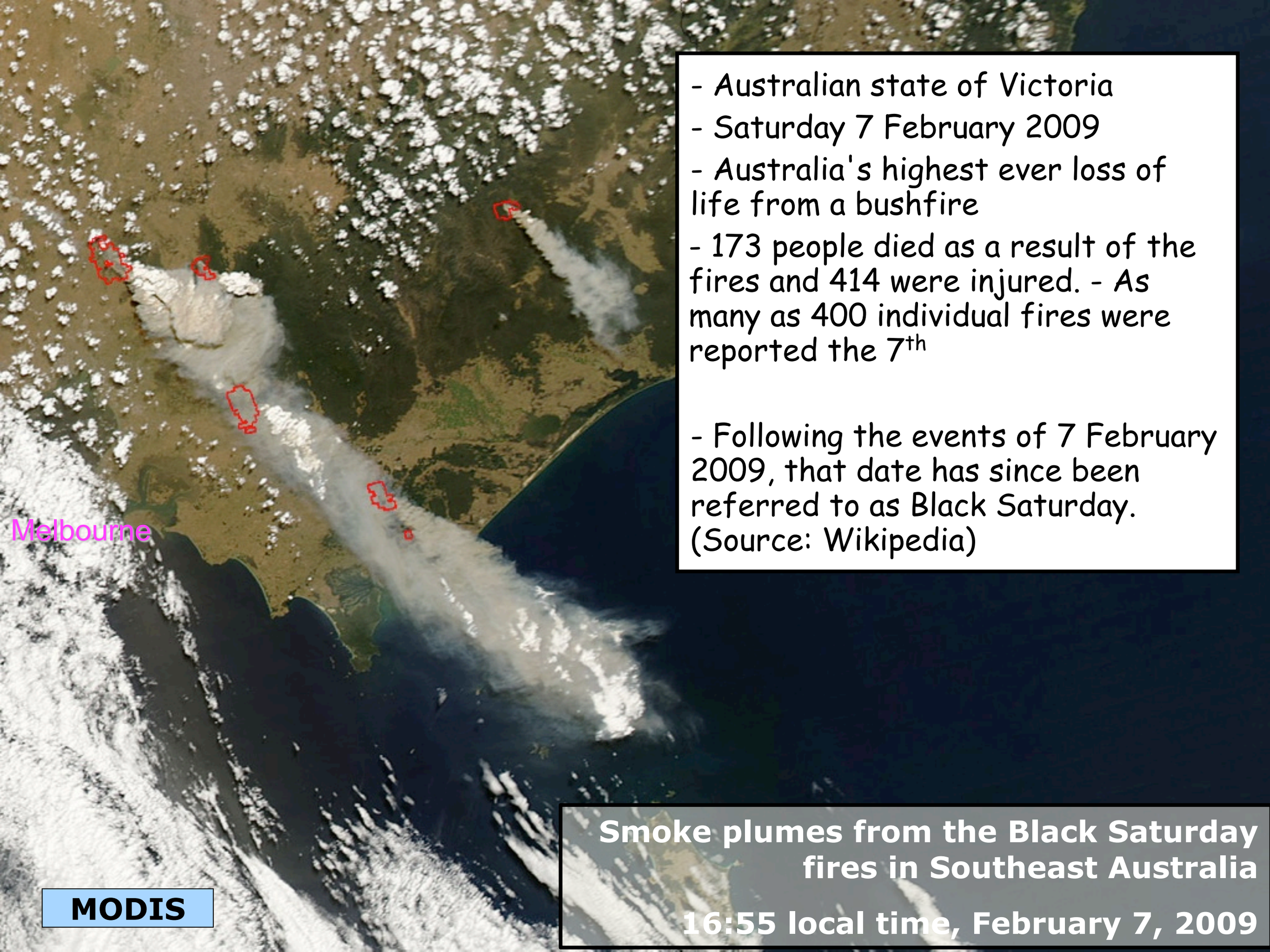
"Thus, assessments of multigas mitigation policies, as well as any separate efforts to mitigate warming from short-lived pollutants, should include gas-aerosol interactions."

Improved Attribution of Climate Forcing to Emissions
Drew T. Shindell, *et al.*
Science **326**, 716 (2009);
DOI: 10.1126/science.1174760

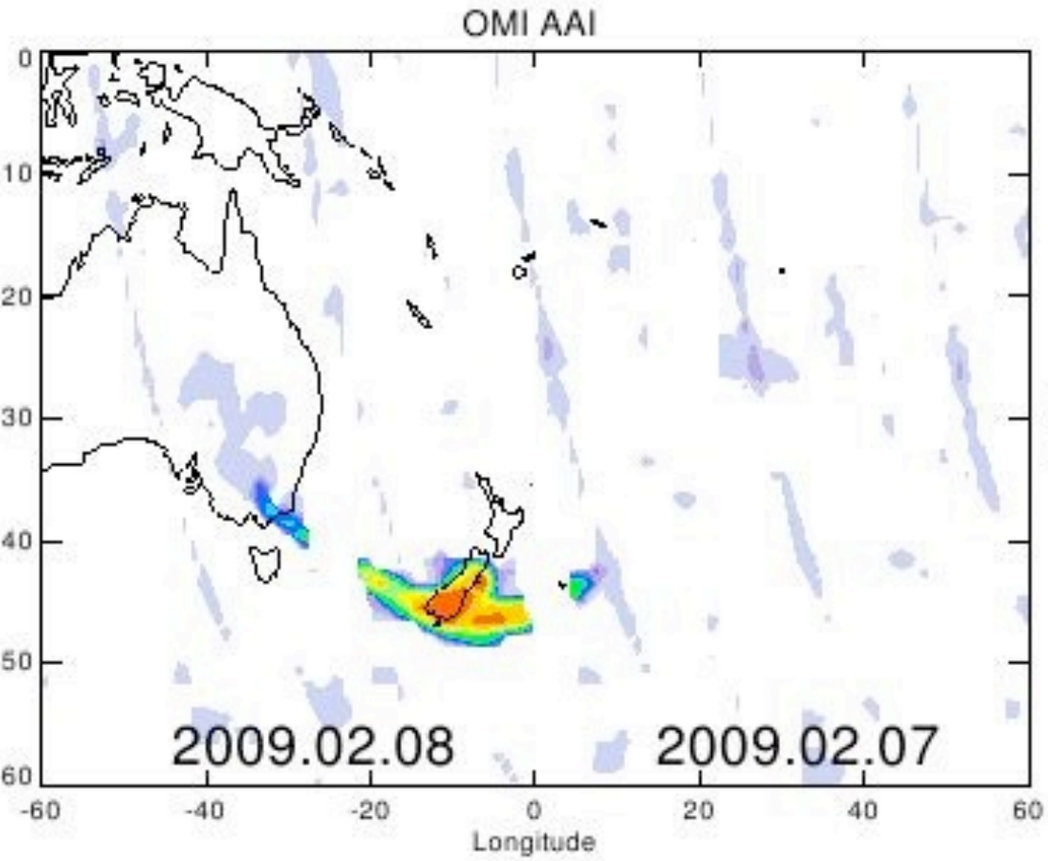
Climate Related A-Train Studies

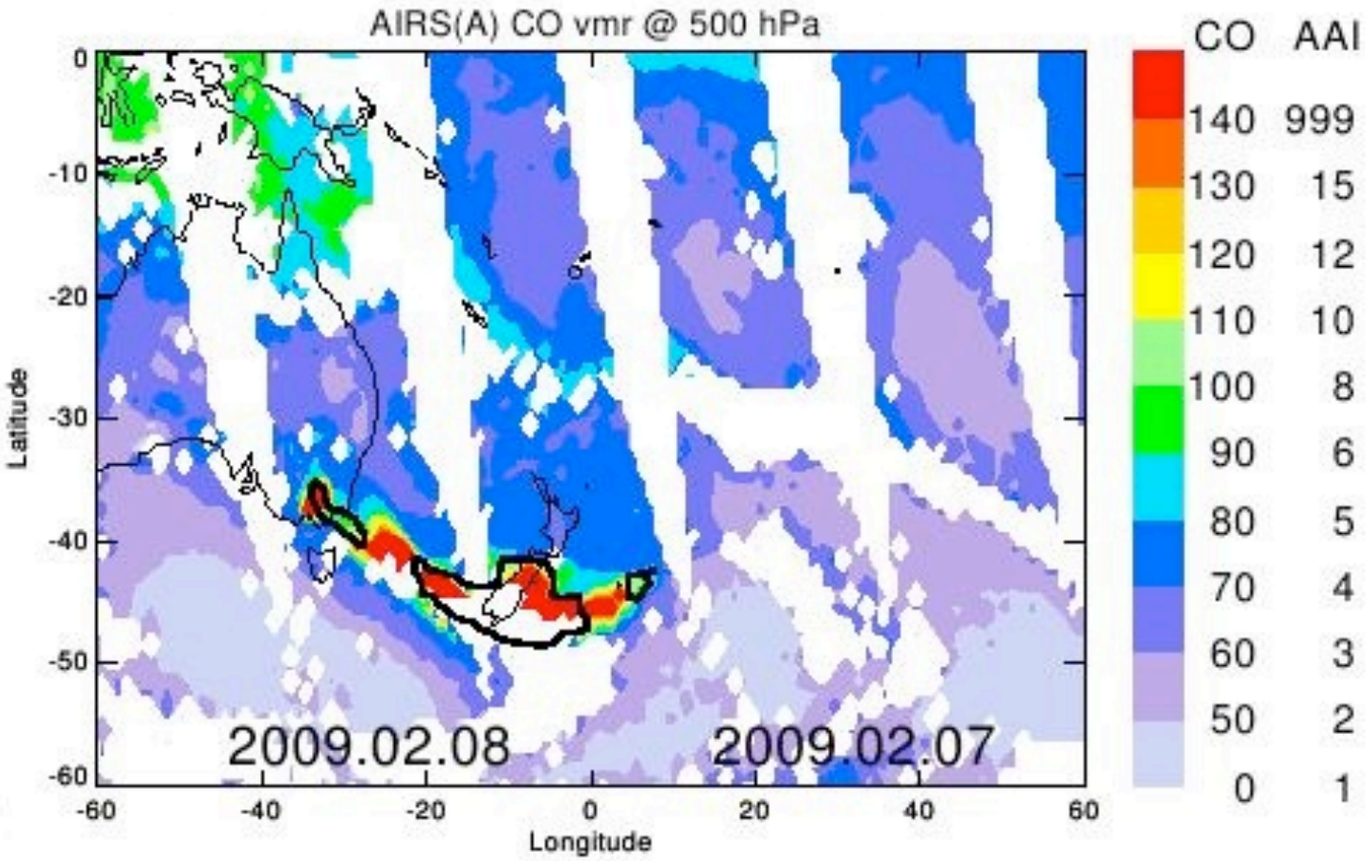
- Effects of absorbing aerosols on the atmospheric stability:
  The Australian black Saturday fires
- Satellite observations of secondary aerosols and their precursors.



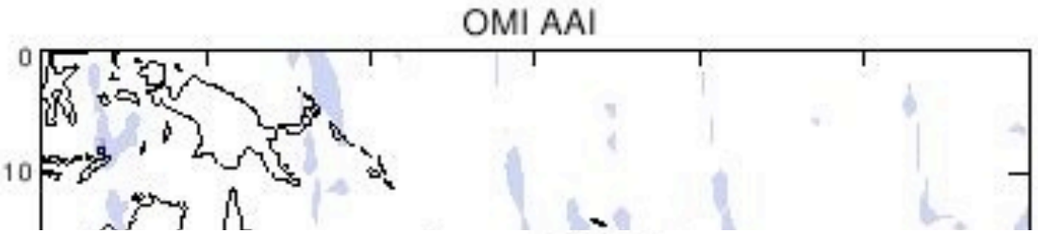

- Australian state of Victoria
- Saturday 7 February 2009
- Australia's highest ever loss of life from a bushfire
- 173 people died as a result of the fires and 414 were injured. - As many as 400 individual fires were reported the 7th
- Following the events of 7 February 2009, that date has since been referred to as Black Saturday. (Source: Wikipedia)
Melbourne
MODIS
Smoke plumes from the Black Saturday fires in Southeast Australia
16:55 local time, February 7, 2009

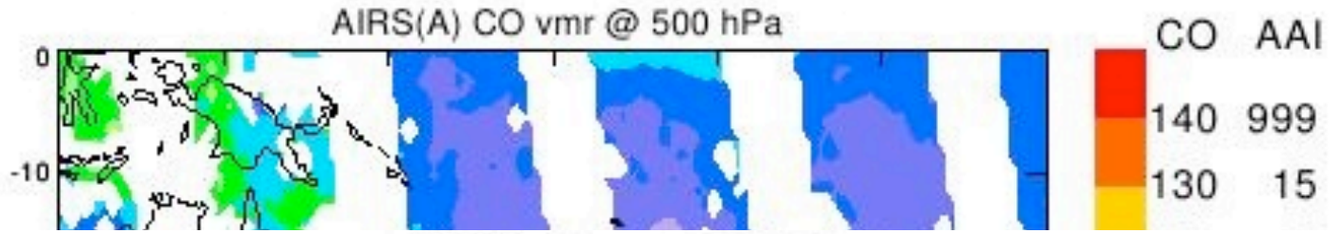
TIMELINE (OMI AAI, AIRS 500 hPa CO)

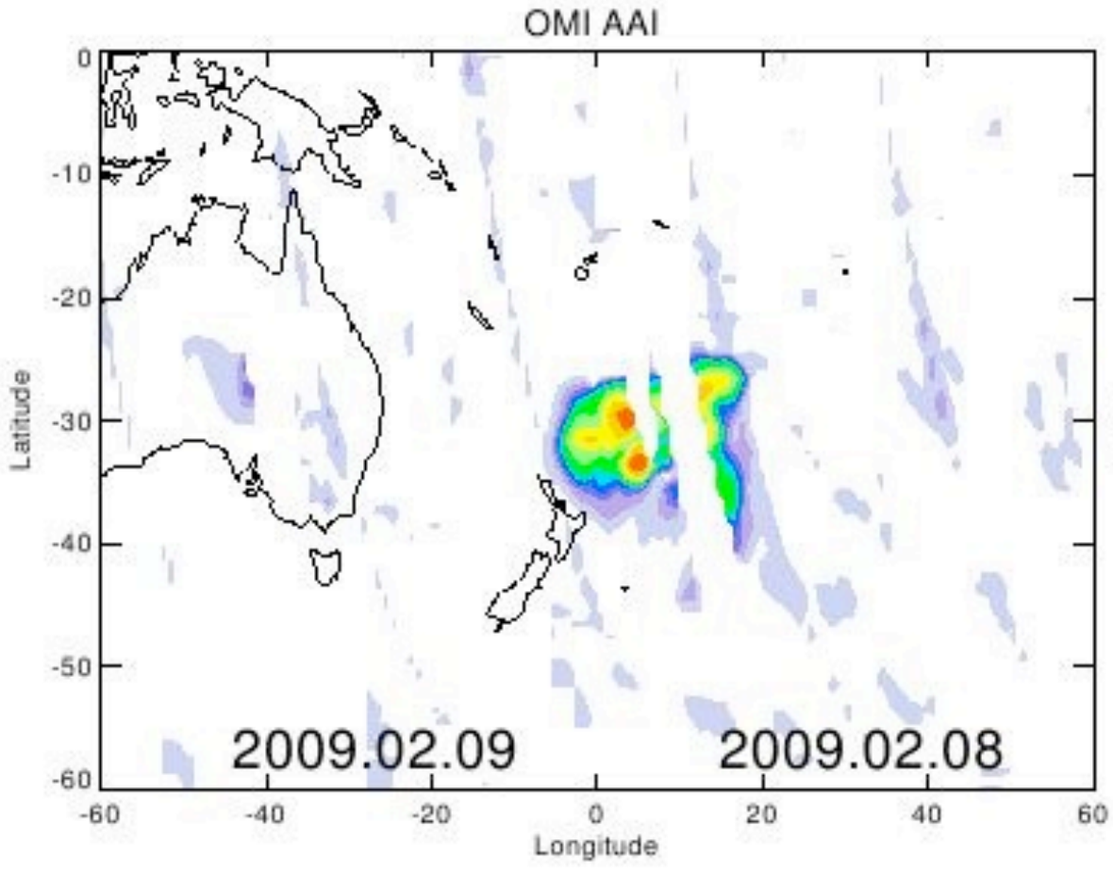


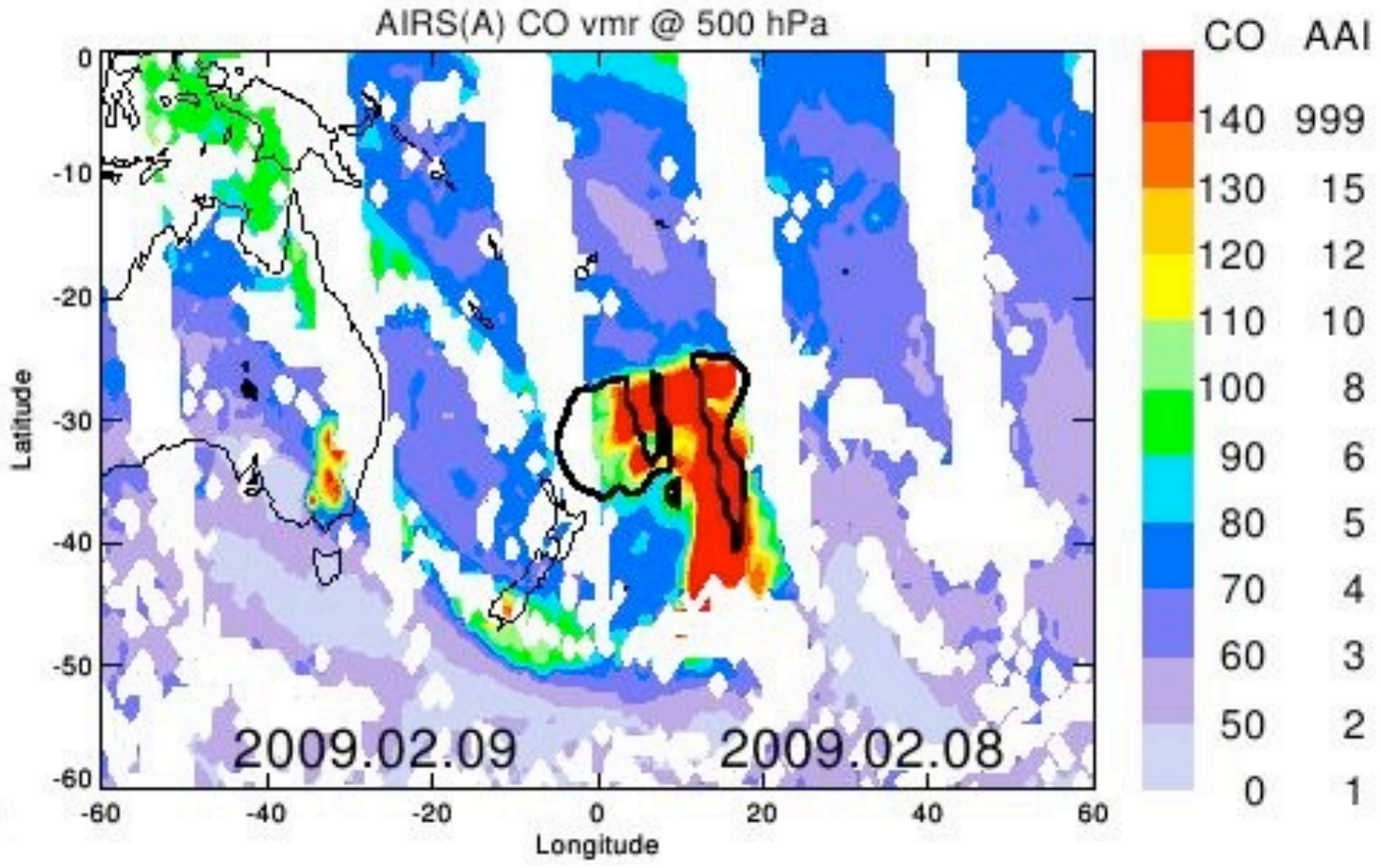


TIMELINE (OMI AAI, AIRS 500 hPa CO)

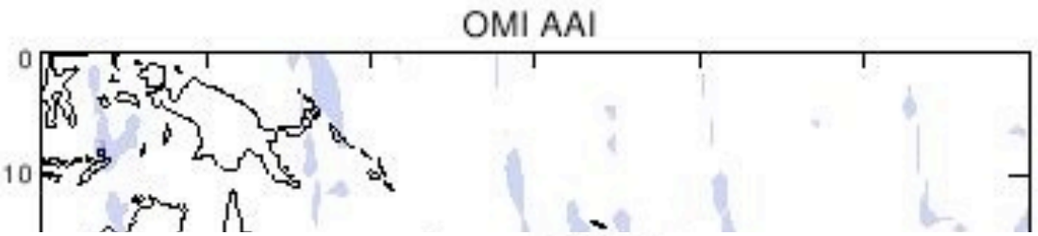


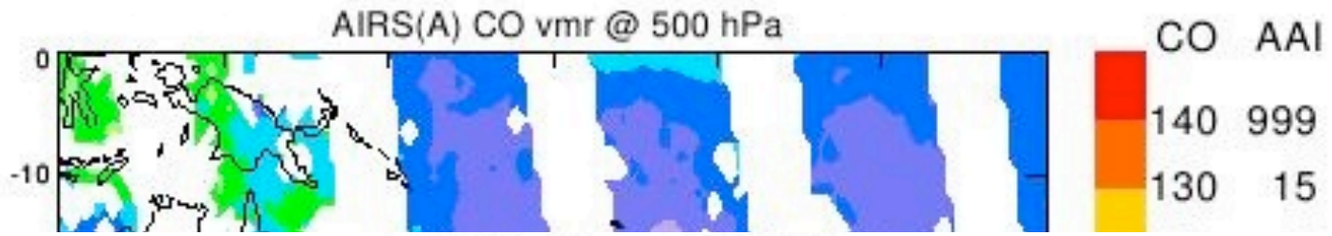


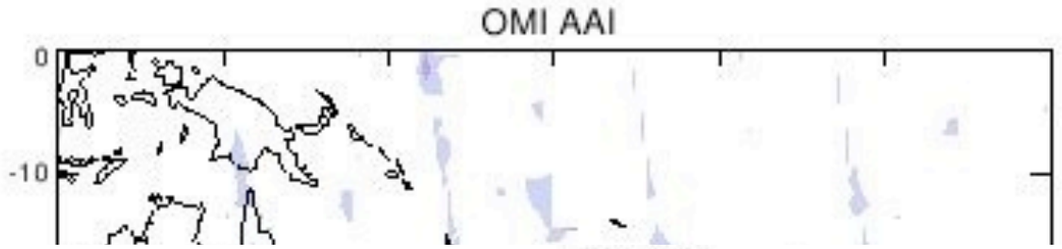


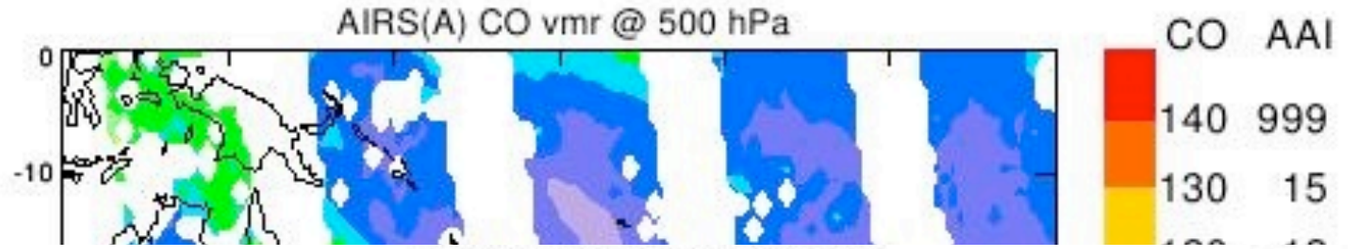


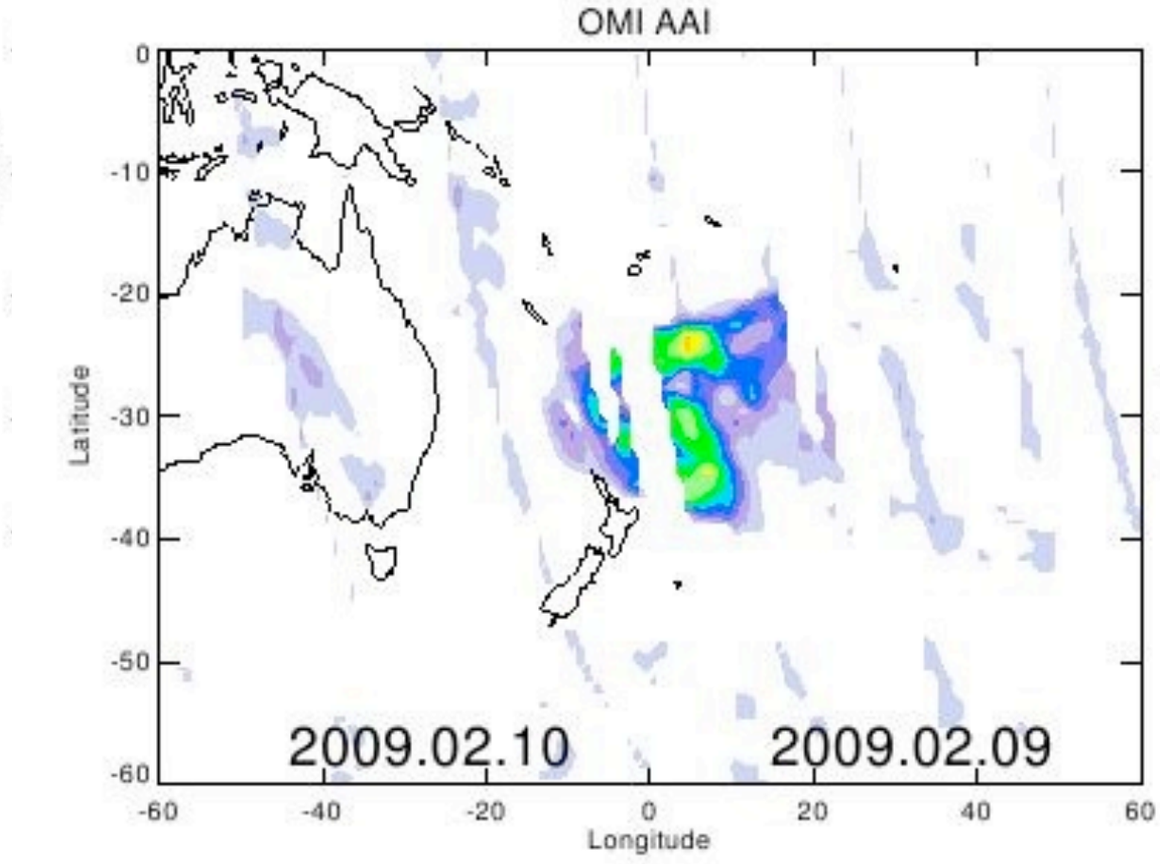
TIMELINE (OMI AAI, AIRS 500 hPa CO)

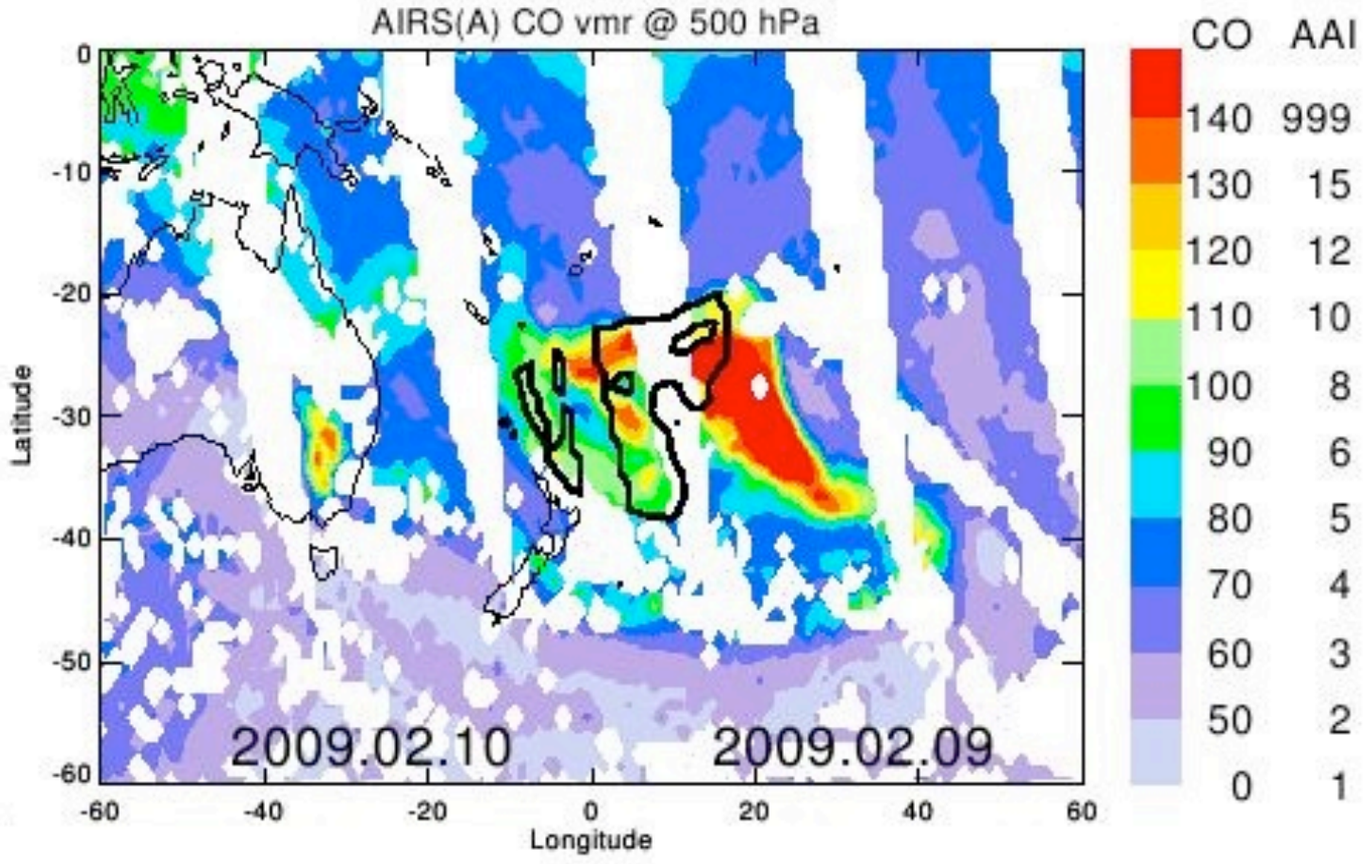












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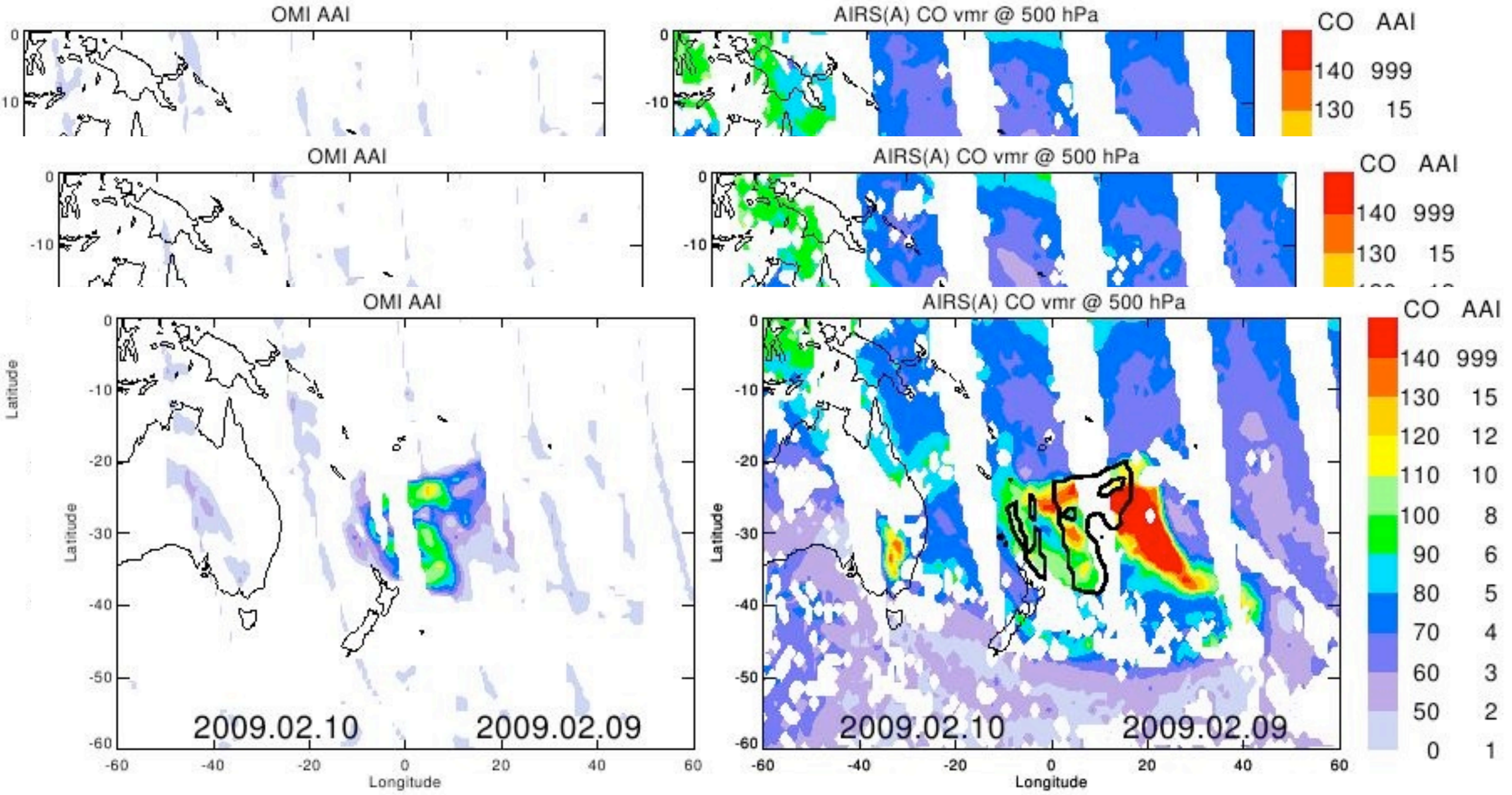
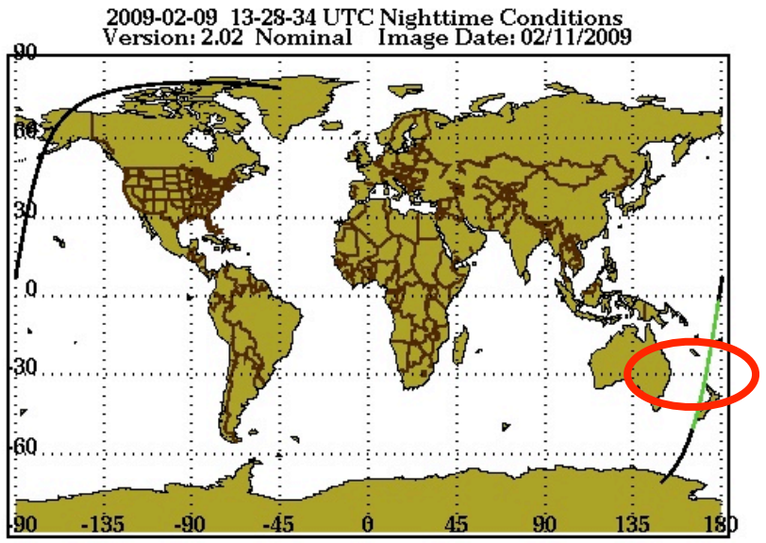
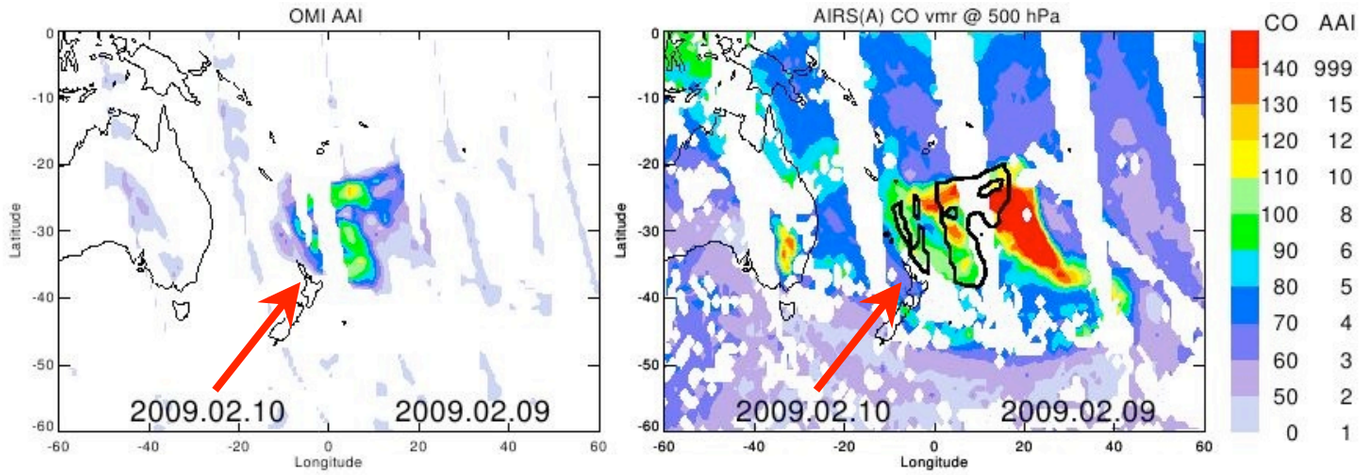


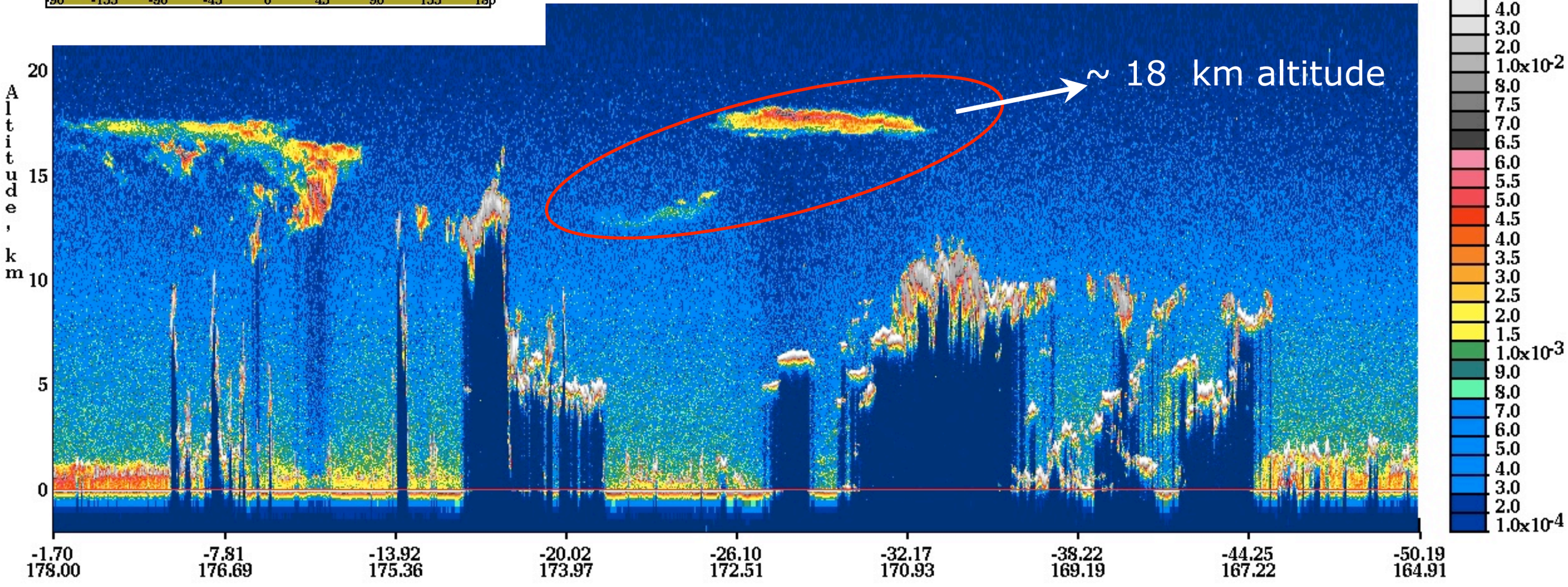
Subsequent slow advection in westerly direction, strongly suggestive that the plume had entered the lower stratosphere. The plume could be traced for many weeks.

CALIPSO: 09 Feb 13:55 – 14:09 UTC

10 Feb 01:55 – 02:09 LT

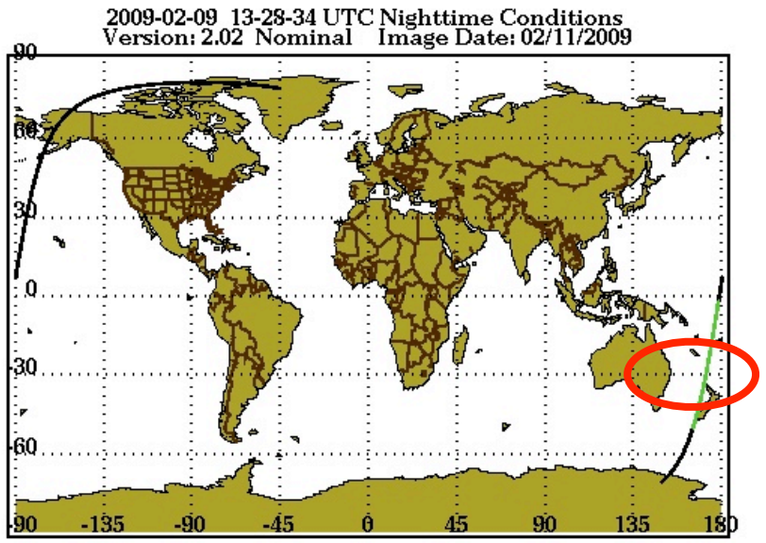


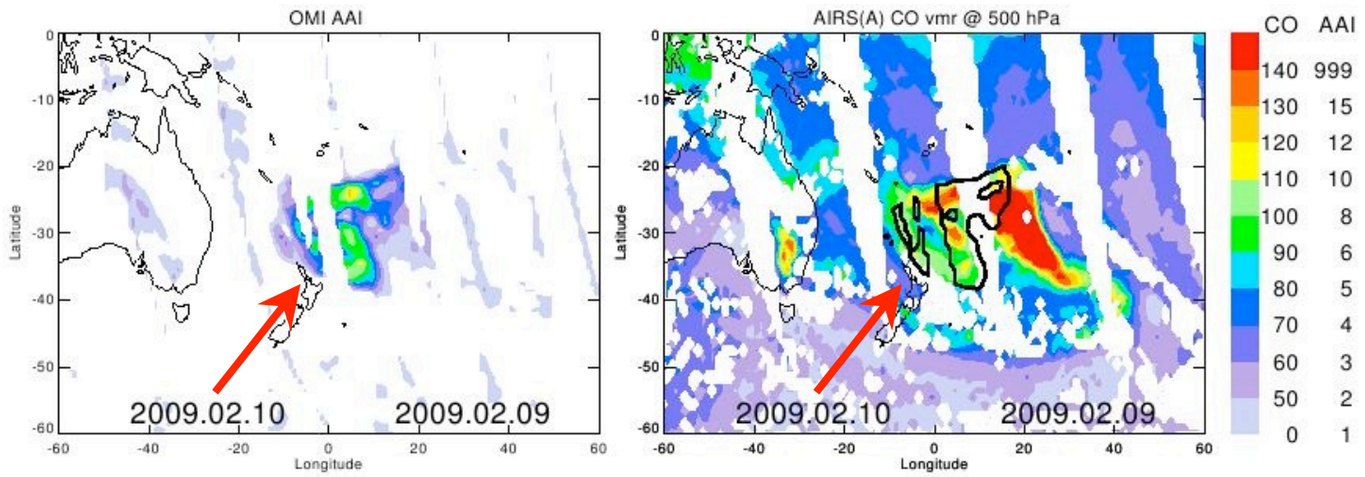


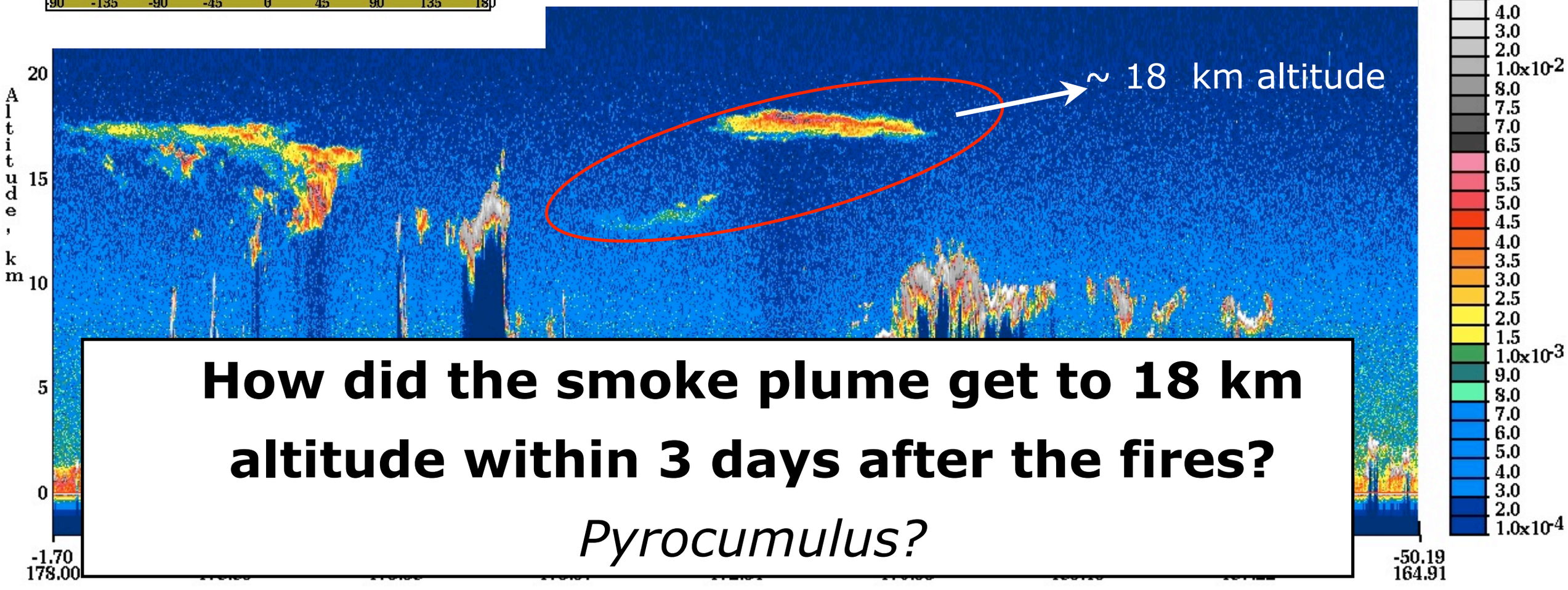


CALIPSO: 09 Feb 13:55 – 14:09 UTC

10 Feb 01:55 – 02:09 LT



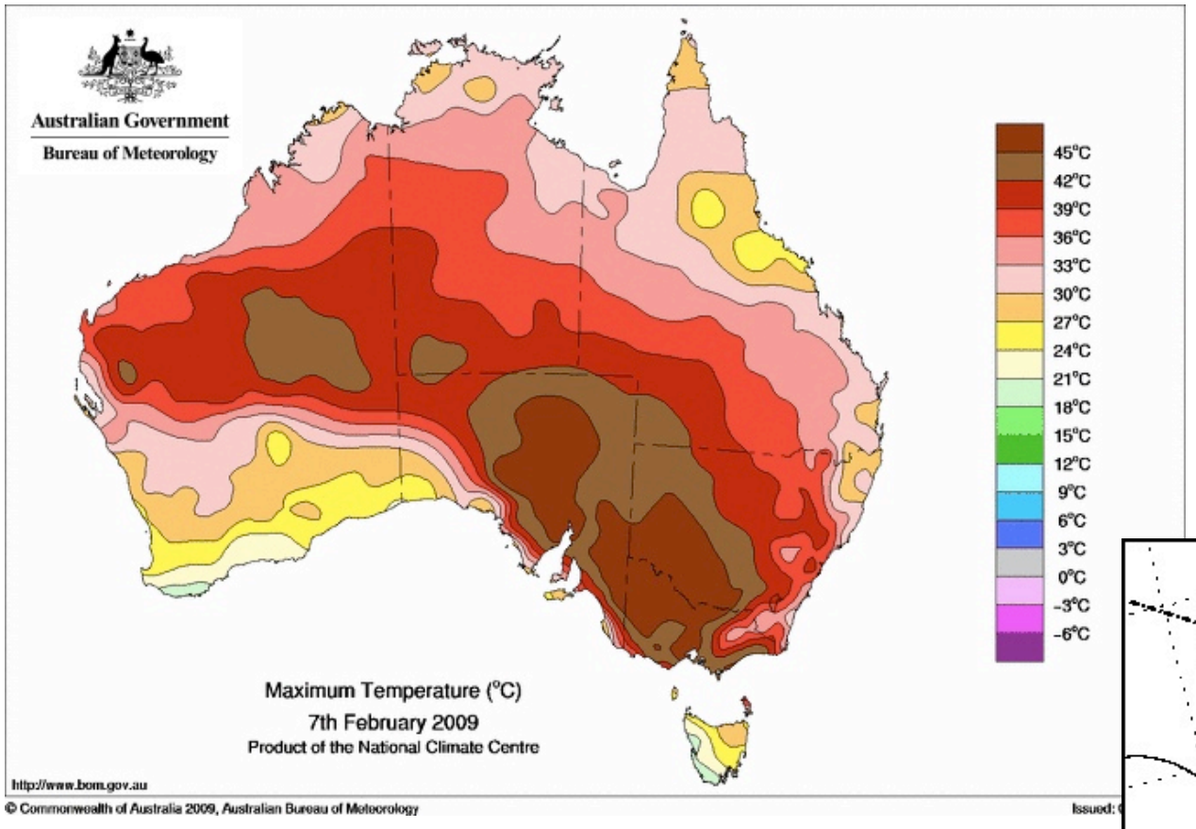


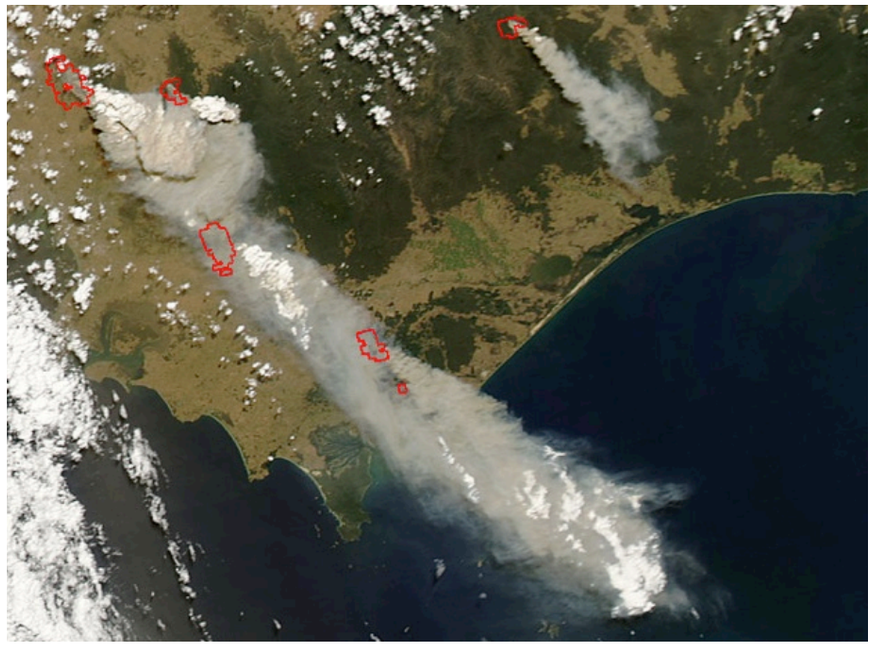


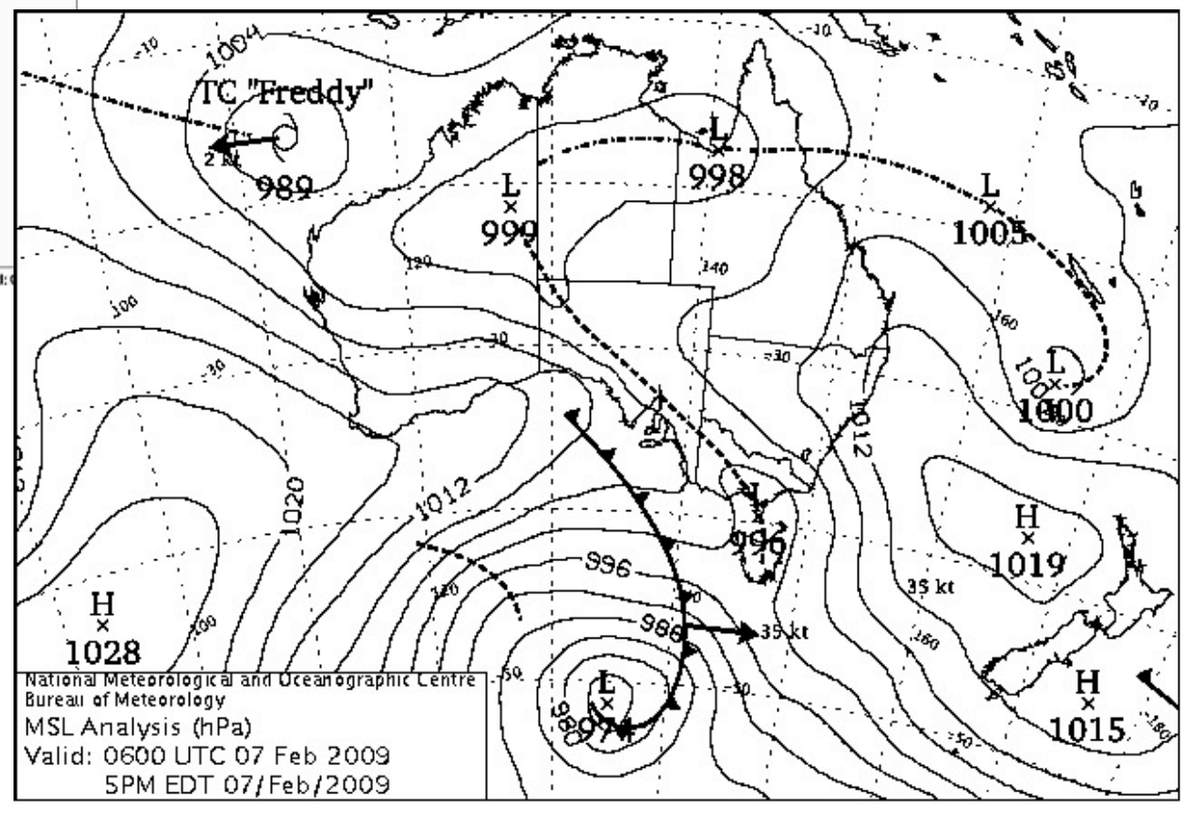
How did the smoke plume get to 18 km altitude within 3 days after the fires?

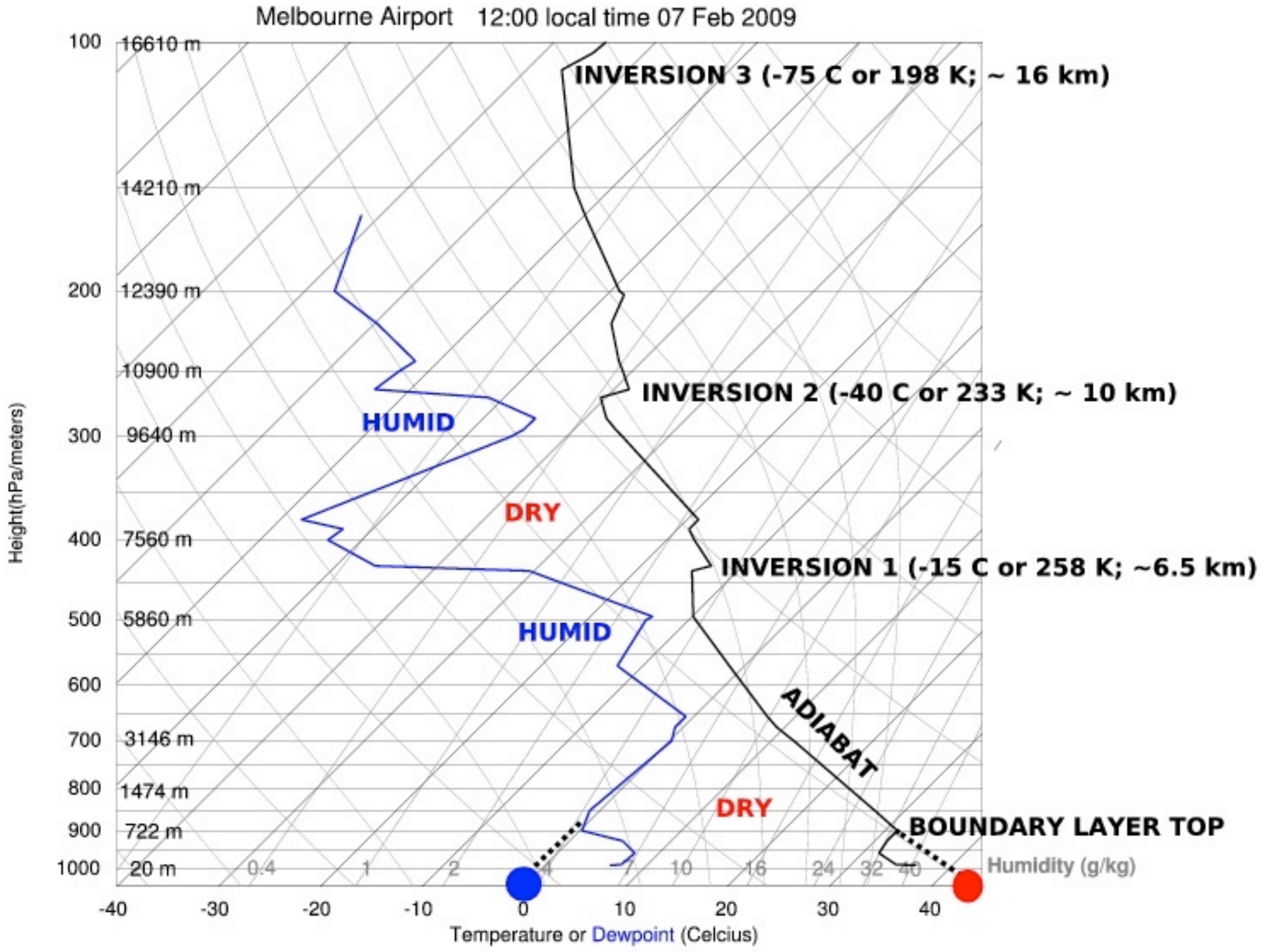
Pyrocumulus?

Meteorological conditions at the time of the fires



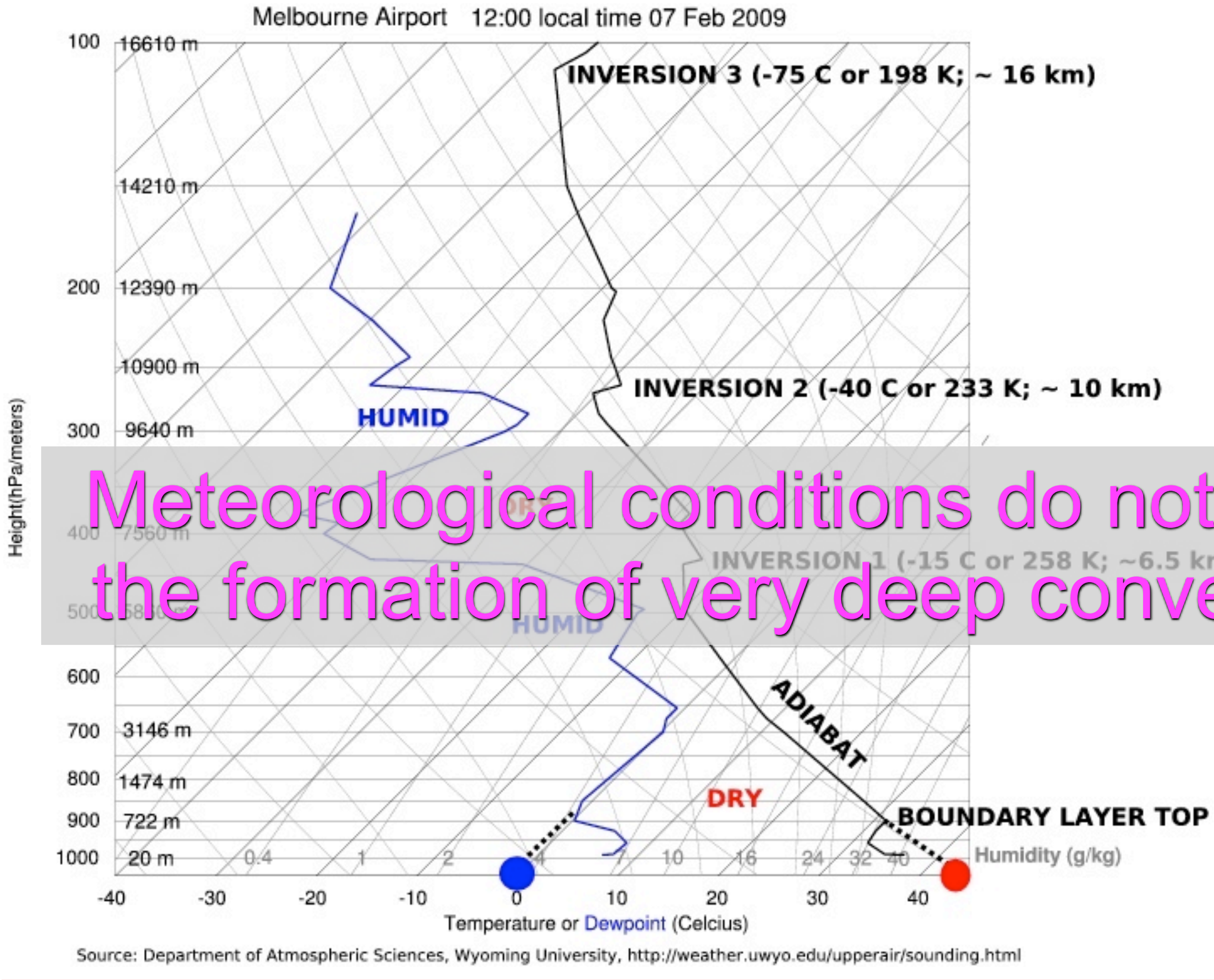






Source: Department of Atmospheric Sciences, Wyoming University, http://weather.uwyo.edu/upperair/sounding.html

1) Boundary layer depth ~ 6 km (!!!)
2) Surface temperature ~ 45°C, dewpoint temperature < 0°C ➔ RH ~ 5-10% (!!!)
3) Strong winds in the lower troposphere (10 minute average up to 100 km/hour)
Boundary layer was deep and very, very dry



Source: Department of Atmospheric Sciences, Wyoming University, http://weather.uwyo.edu/upperair/sounding.html

Meteorological conditions do not favor the formation of very deep convection

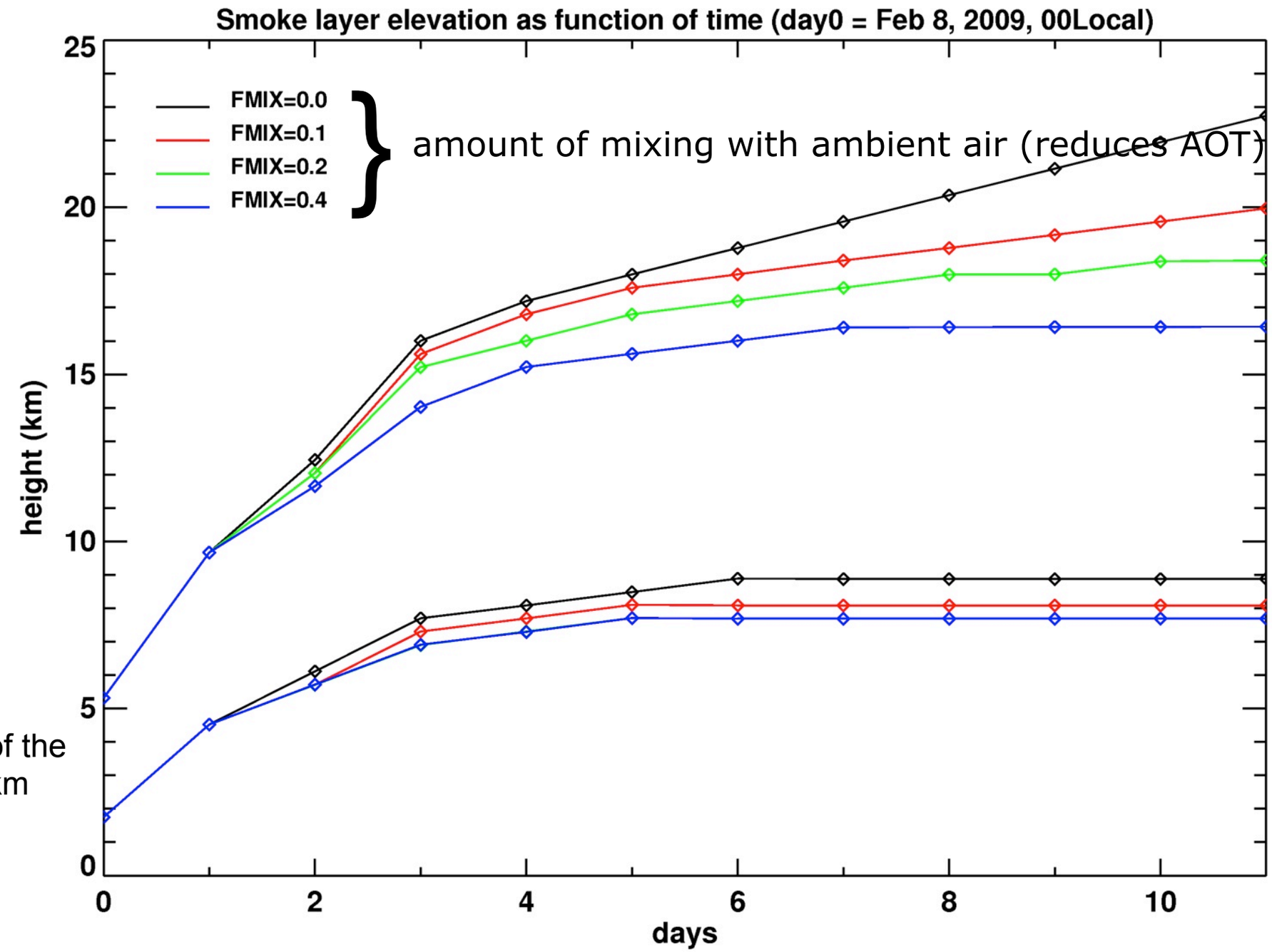
1) Boundary layer depth ~ 6 km (!!!)
2) Surface temperature ~ 45°C, dewpoint temperature < 0°C ➔ RH ~ 5-10% (!!!)
3) Strong winds in the lower troposphere (10 minute average up to 100 km/hour)
Boundary layer was deep and very, very dry

Self-lifting of absorbing aerosol: a simple model

- Broadband shortwave radiative transfer model
- Start with an aerosol layer between 2-5 km altitude
- Aerosol optical properties from local observations
- Warming → changes potential temperature → Melbourne temperature profile as background atmosphere → vertical displacement
- No condensation and latent heat release is assumed to occur

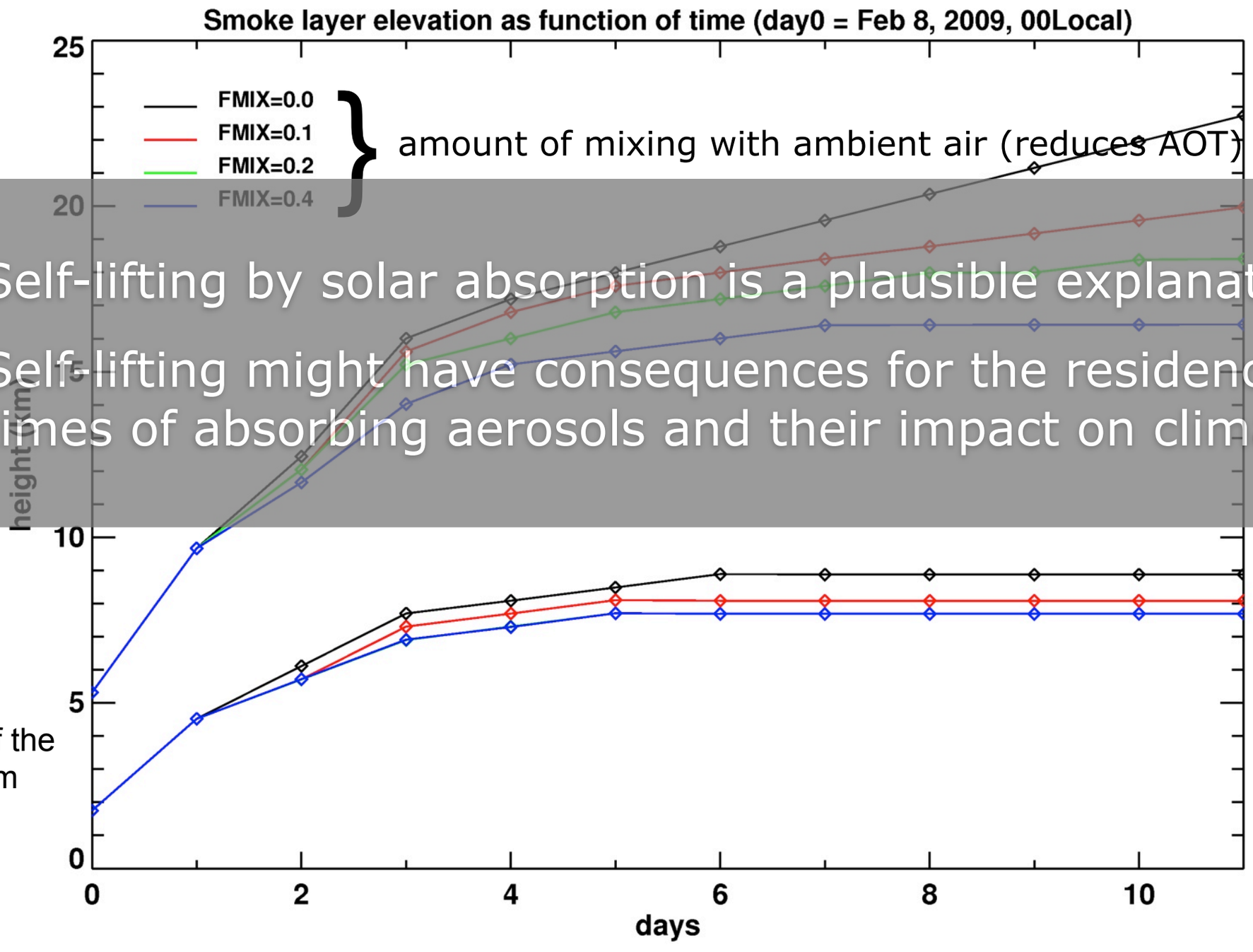
The theoretical background, the model and the calculations are explored in more detail in Boers et al. [2010], accepted for GRL.

The vertical translation as a function of mixing with the environment



Initial height of the plume:2-5km

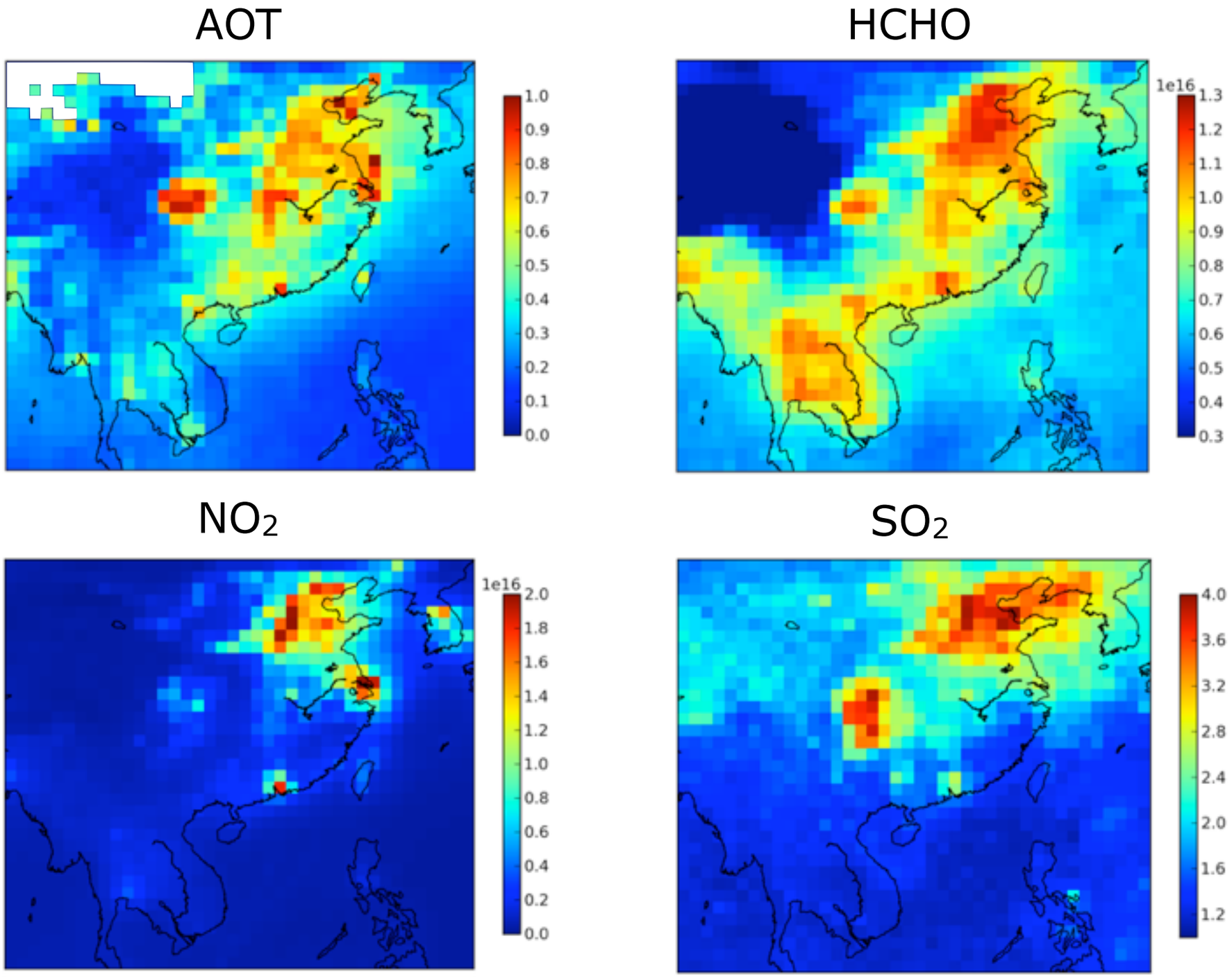
The vertical translation as a function of mixing with the environment



Initial height of the plume:2-5km

Self-lifting by solar absorption is a plausible explanation.

Self-lifting might have consequences for the residence times of absorbing aerosols and their impact on climate.

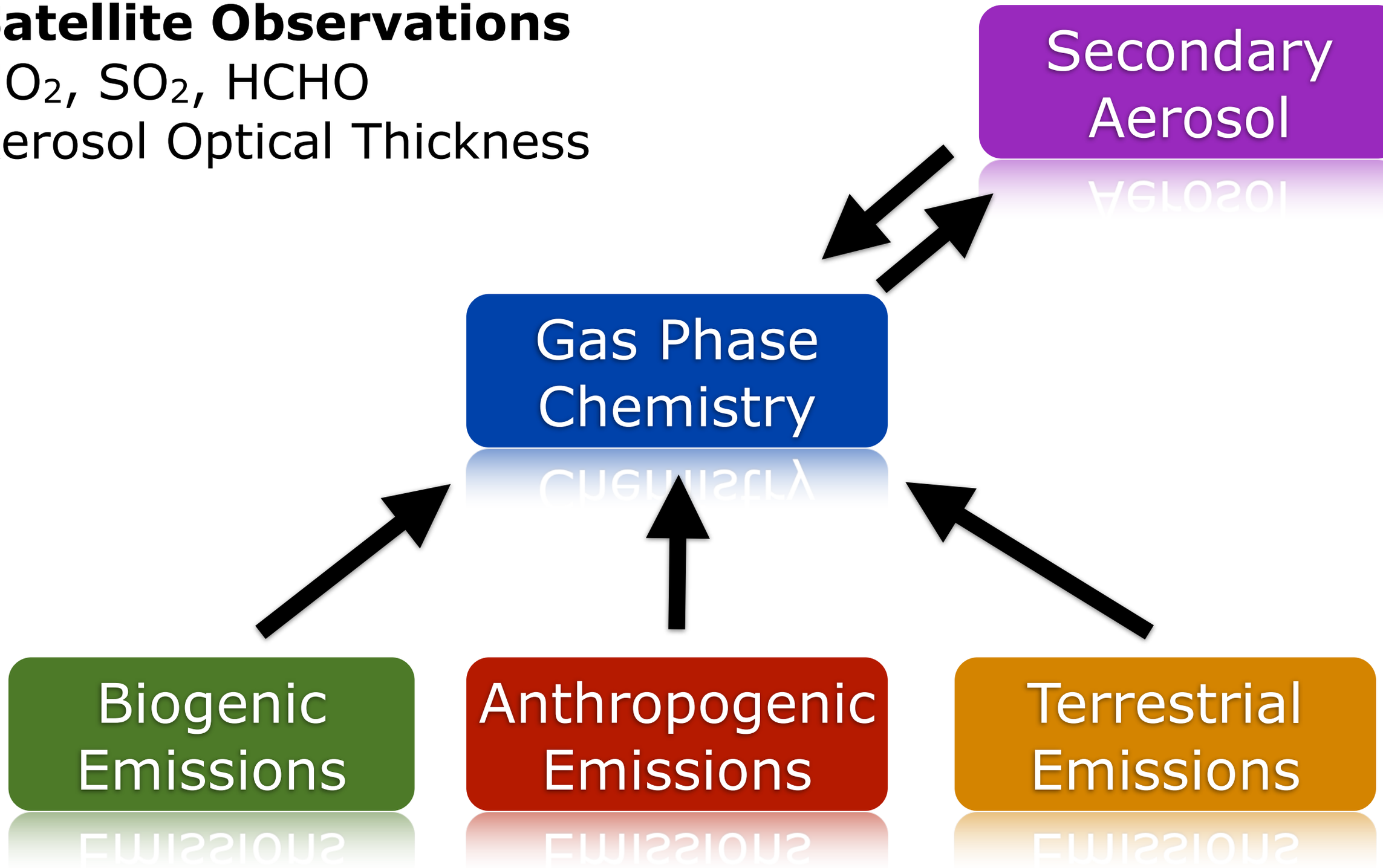


Global analysis of the relation between aerosols and short-lived trace gases

J. P. Veefkind[1], K. F. Boersma[1], J. Wang[2], T. Kurosu[3], N. Krotkov[4], and P. F. Levelt[1,5]

Atmos. Chem. Phys. Discuss., 10, 18919–18951, 2010
www.atmos-chem-phys-discuss.net/10/18919/2010/
doi:10.5194/acpd-10-18919-2010

Satellite Observations
NO_2, SO_2, HCHO
Aerosol Optical Thickness



Emission Sources

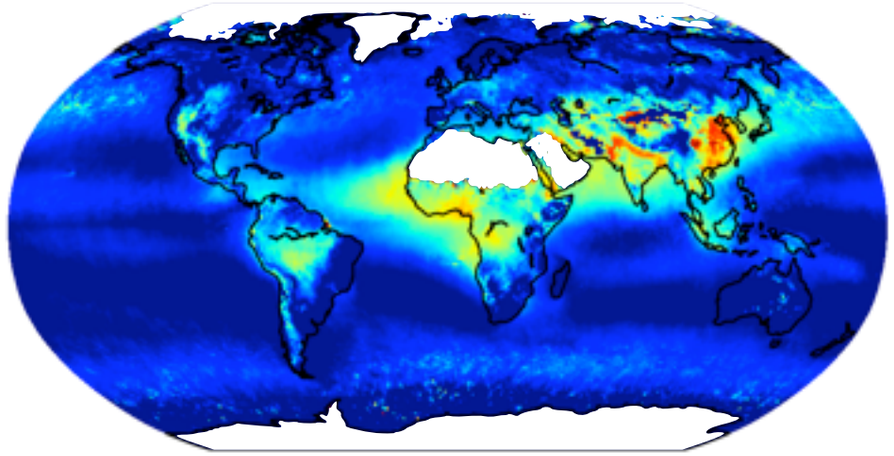
Source	NO_x	HCHO	SO_2	Aerosol
Fossil Fuel Combustion	✓	✓	✓	✓
Biomass Burning	✓	✓		✓
Desert Dust				✓
Sea Spray				✓
Biogenic		✓		✓
Lightning	✓			
Soils	✓			
Volcanoes			✓	✓

Data Sets

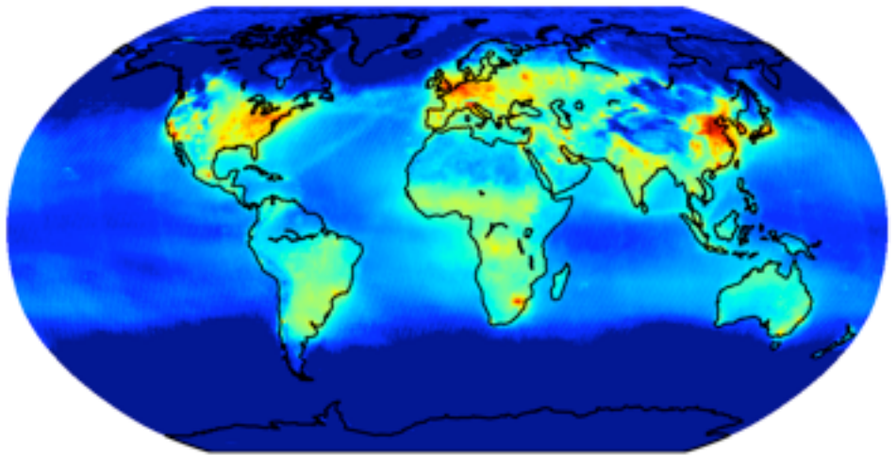
- MODIS AOT Level 3 2005-2007
- OMI KNMI NO_2 Level 3 2005-2007
- OMI HCHO, Level 3 2005-2007
- OMI PBL SO_2, Level 2 2005-2007
- GEOS-Chem 2x2.5° 2005

All data sets have been regridded to seasonal averages on a 1x1° grid

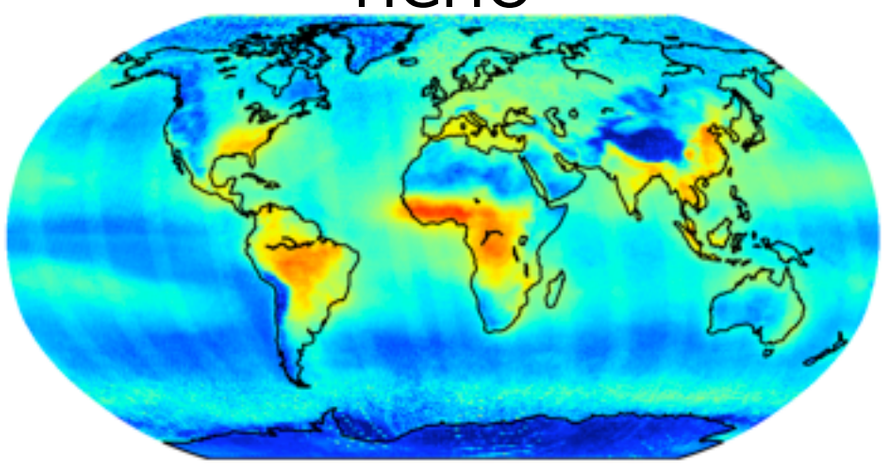
AOT



NO_2

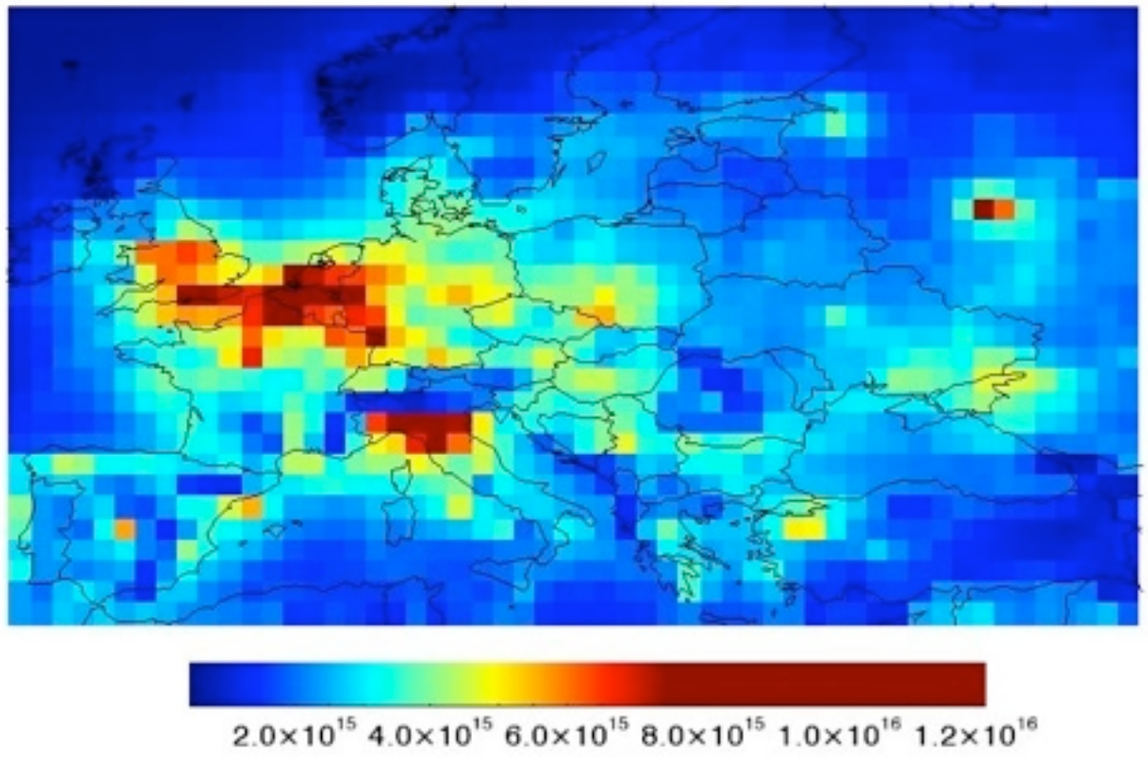


HCHO

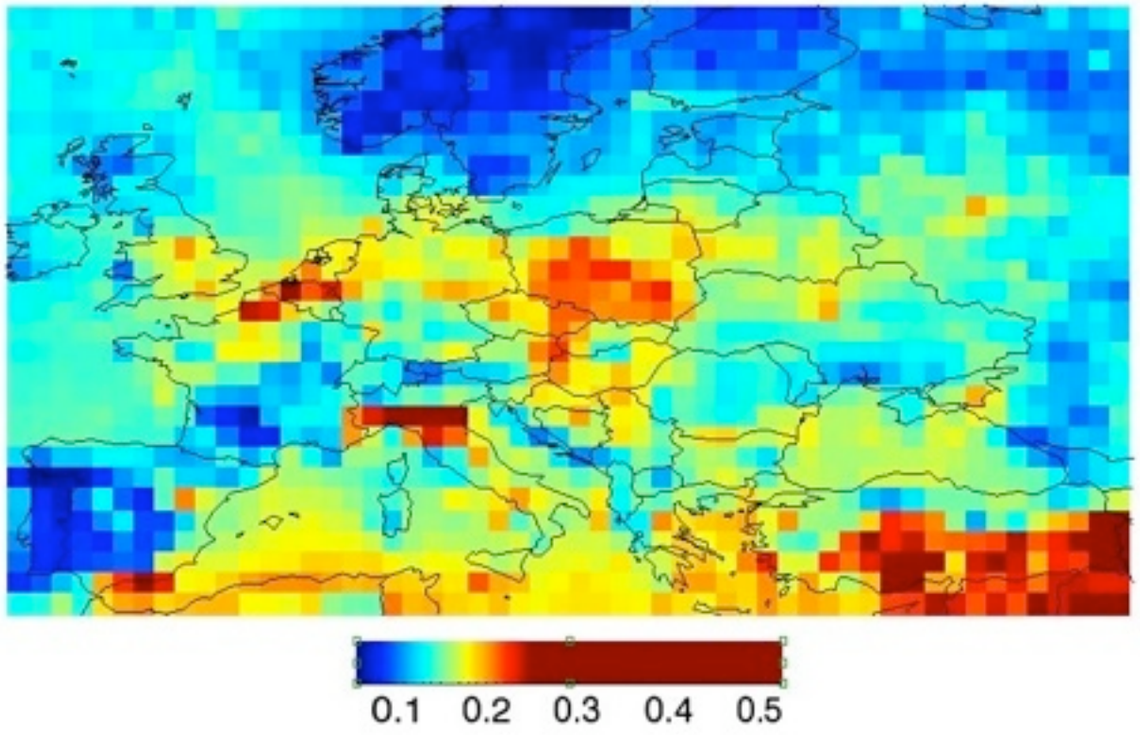


OMI NO_2 and MODIS AOT

OMI Tropospheric NO_2



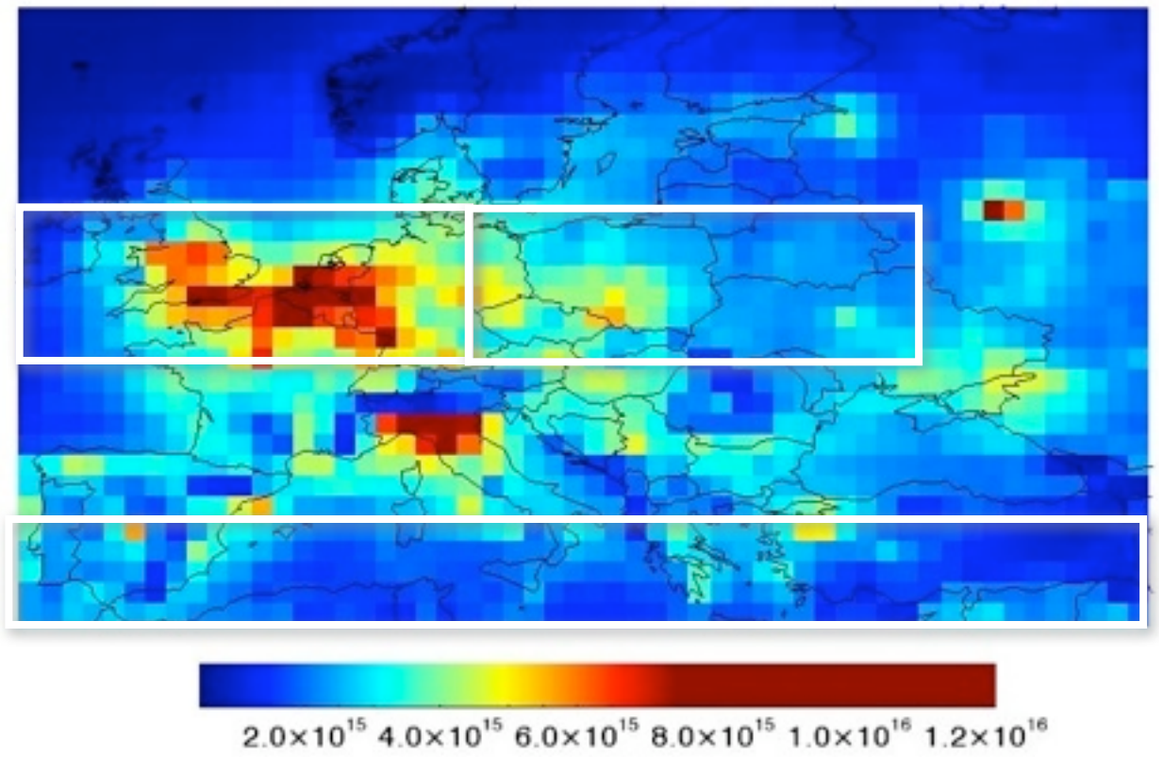
MODIS AOT at 550 nm



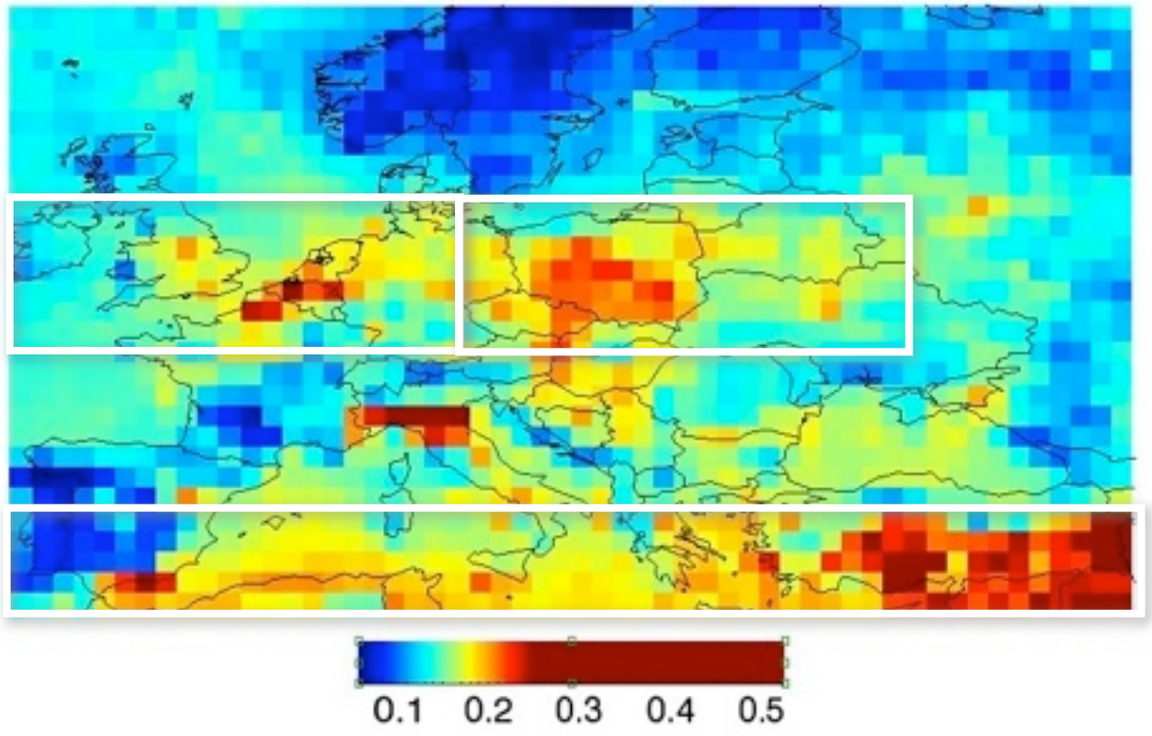
Time period 2005-2007
Gridded 1x1 degree

OMI NO_2 and MODIS AOT

OMI Tropospheric NO_2



MODIS AOT at 550 nm



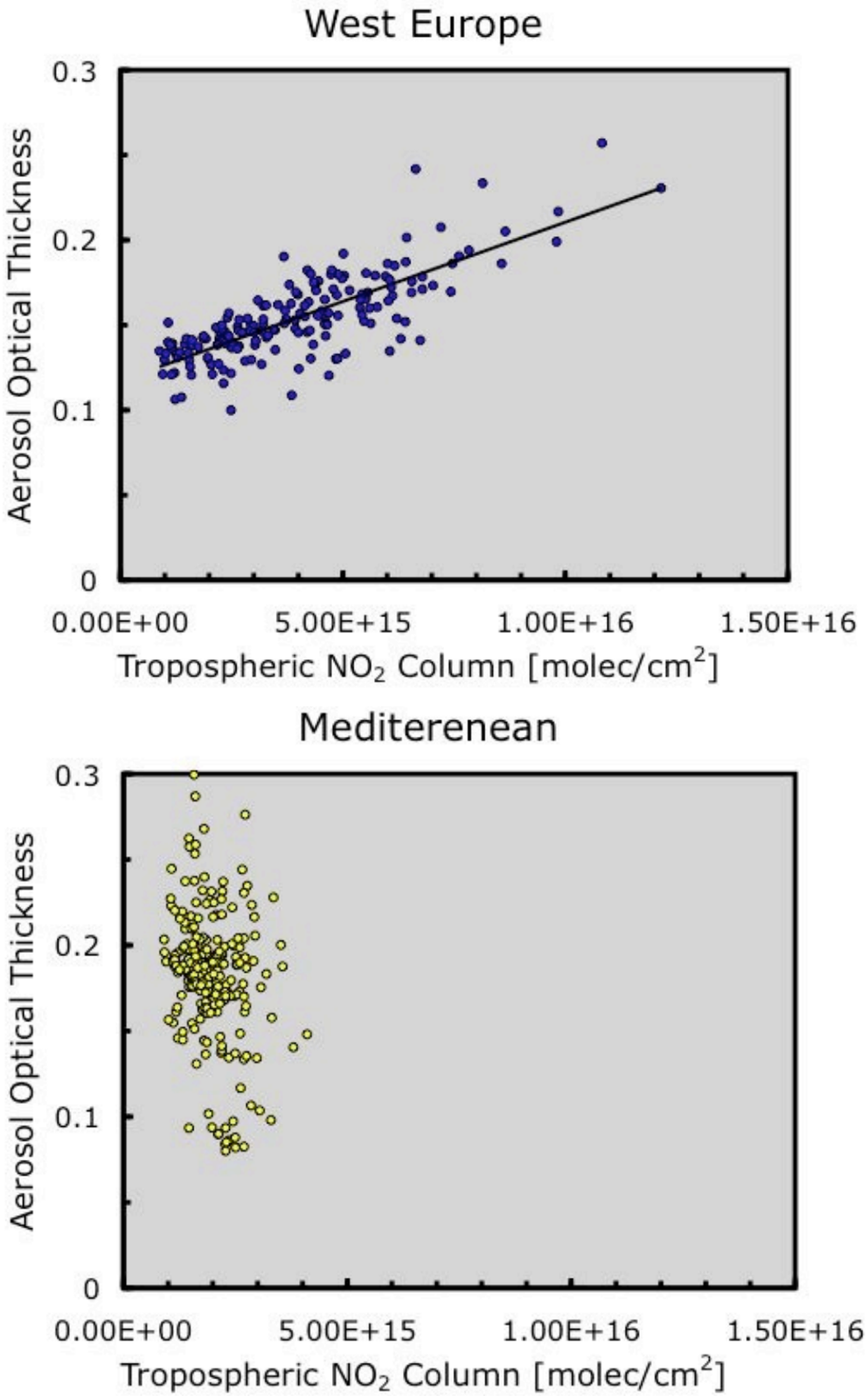
Time period 2005-2007
Gridded 1x1 degree

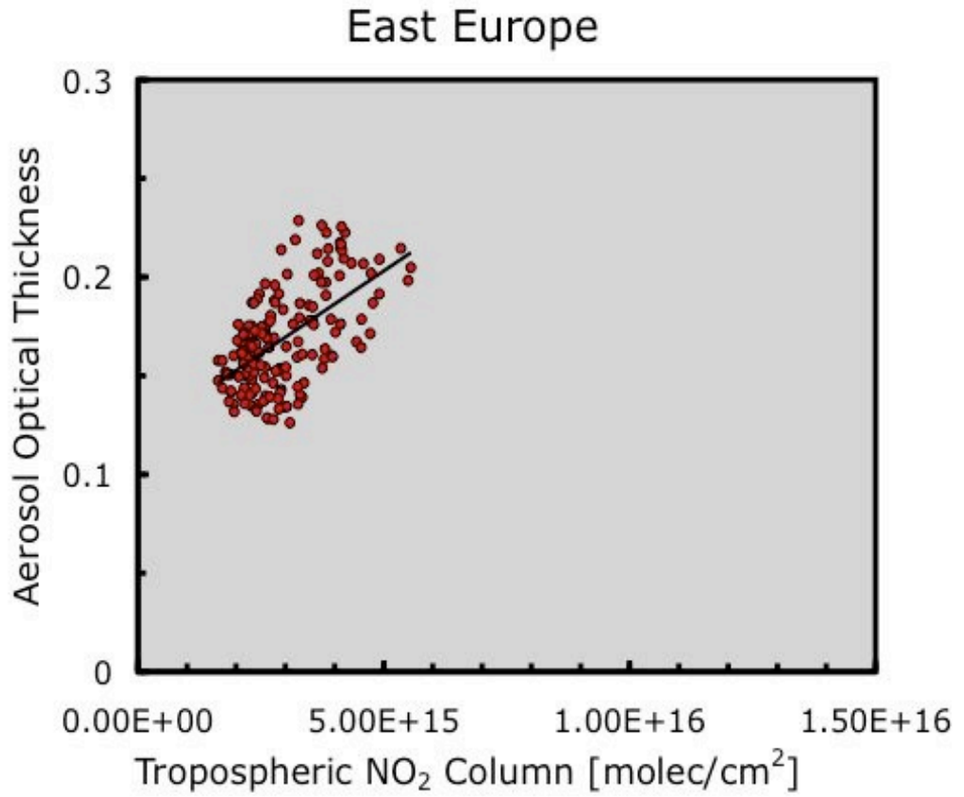
West Europe

East Europe

Mediterranean

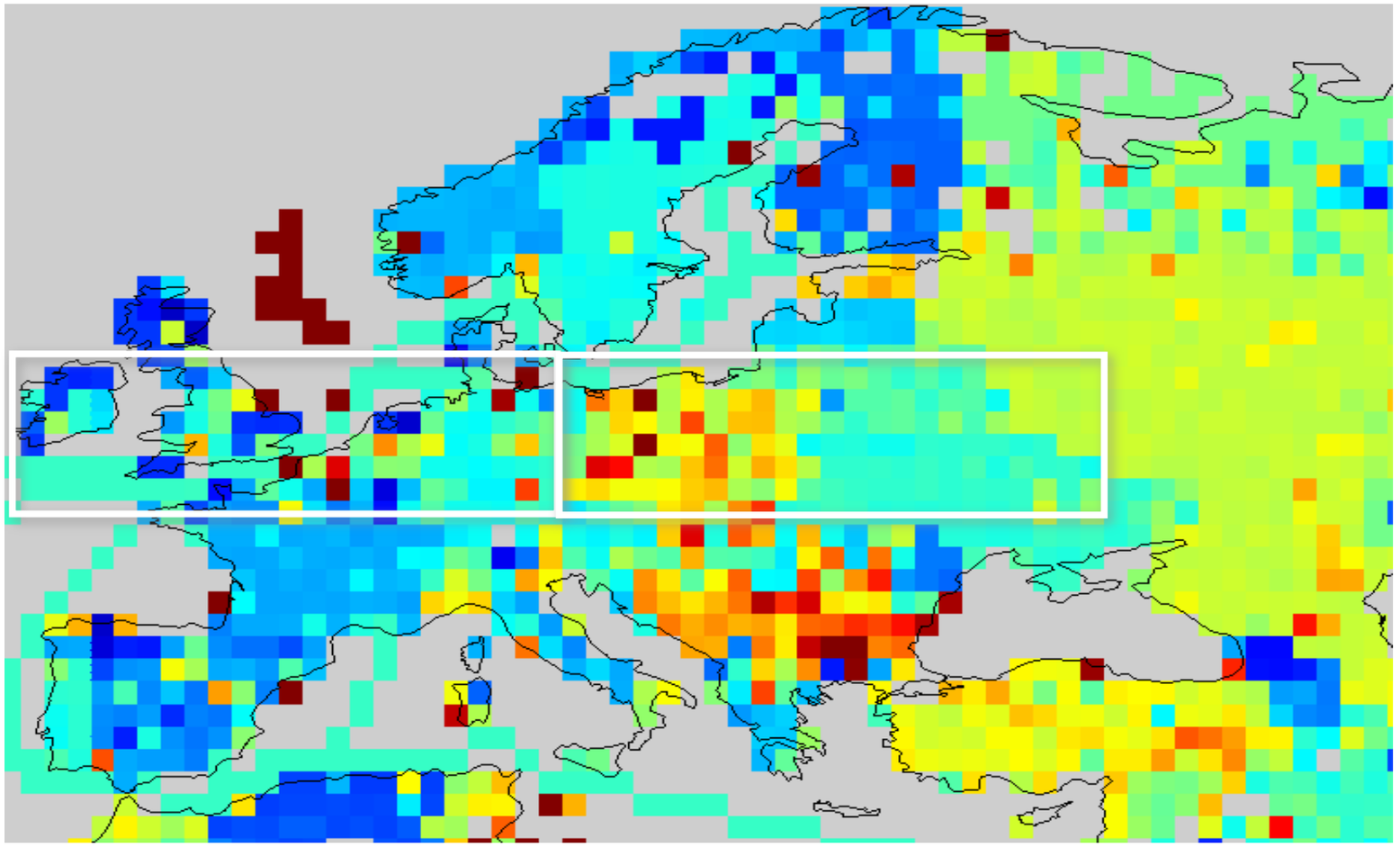
AOT - NO_2 Spatial Correlation

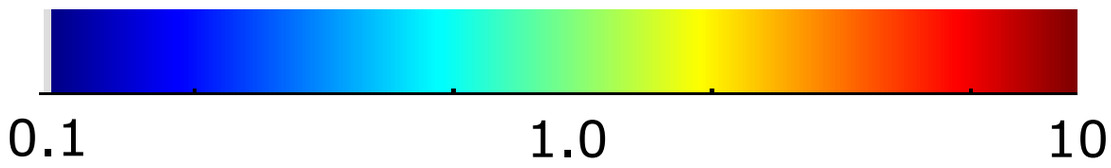




Region	Correlation	Slope
West Europe	0.79	0.93 10^{-17}
East Europe	0.58	1.68 10^{-17}
Mediterranean	-0.20	N/a

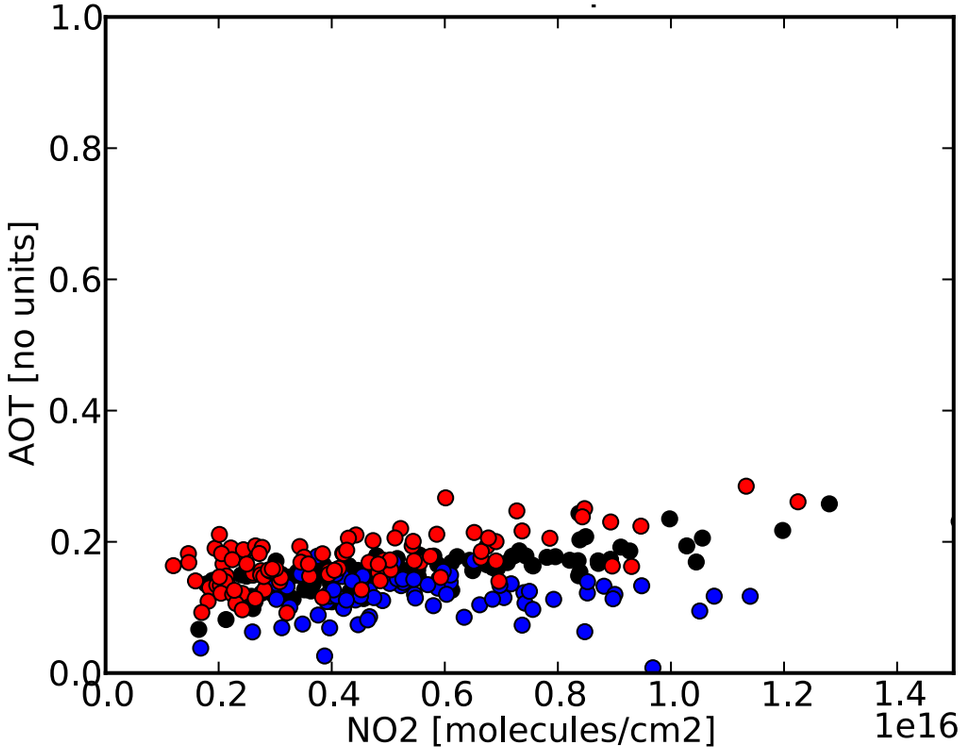
Ratio SO_2 to NO_x in Europe from the EDGAR Database

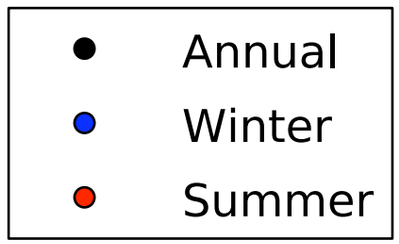




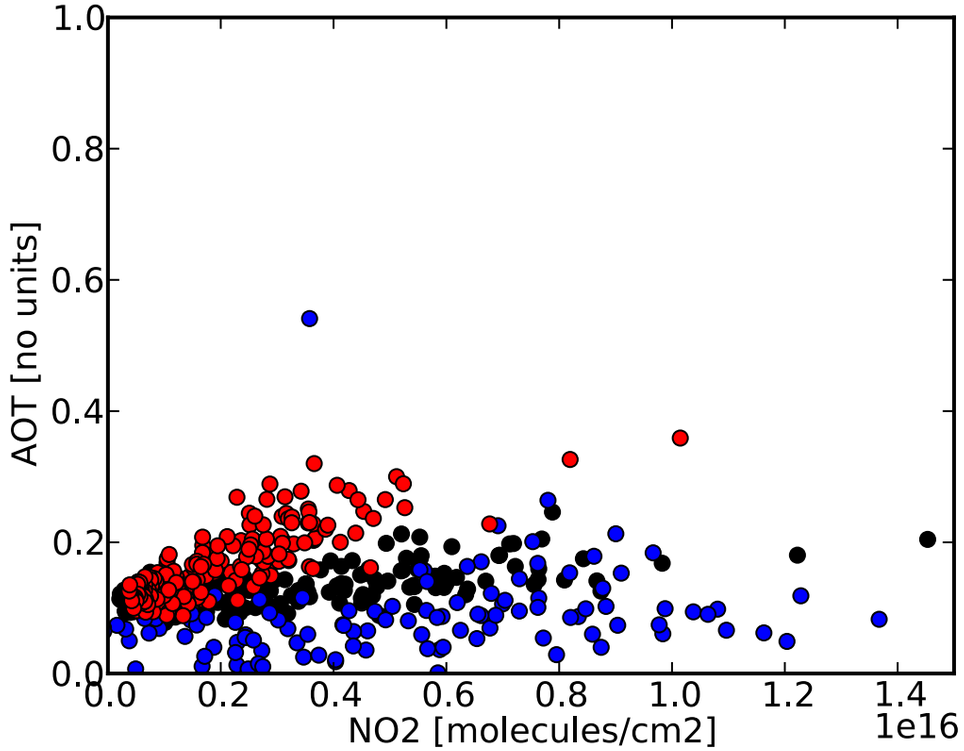
In Eastern Europe more SO_x is emitted per unit NO_x, leading to more aerosol mass per unit NO_x and to a larger slope between the NO_2 concentration and AOT

West-Europe

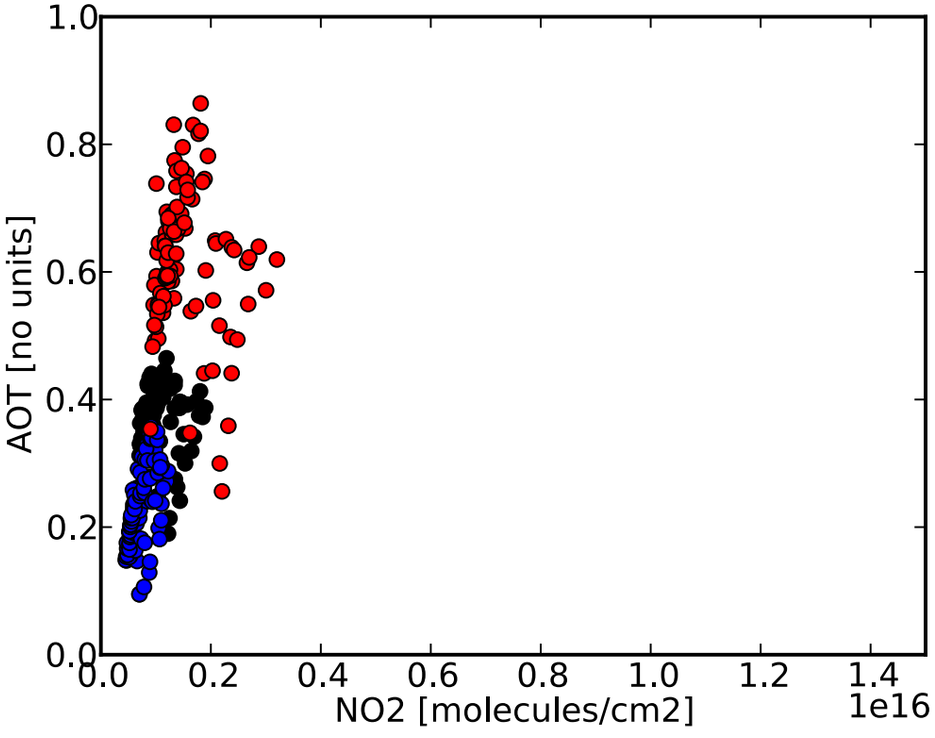




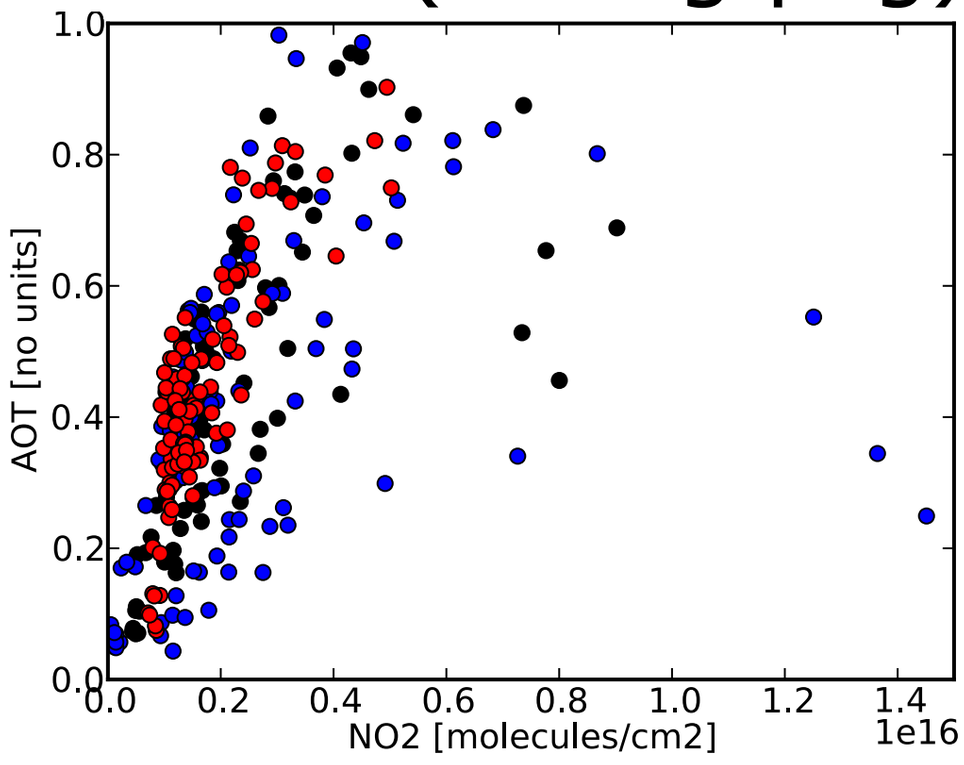
East USA



West Africa



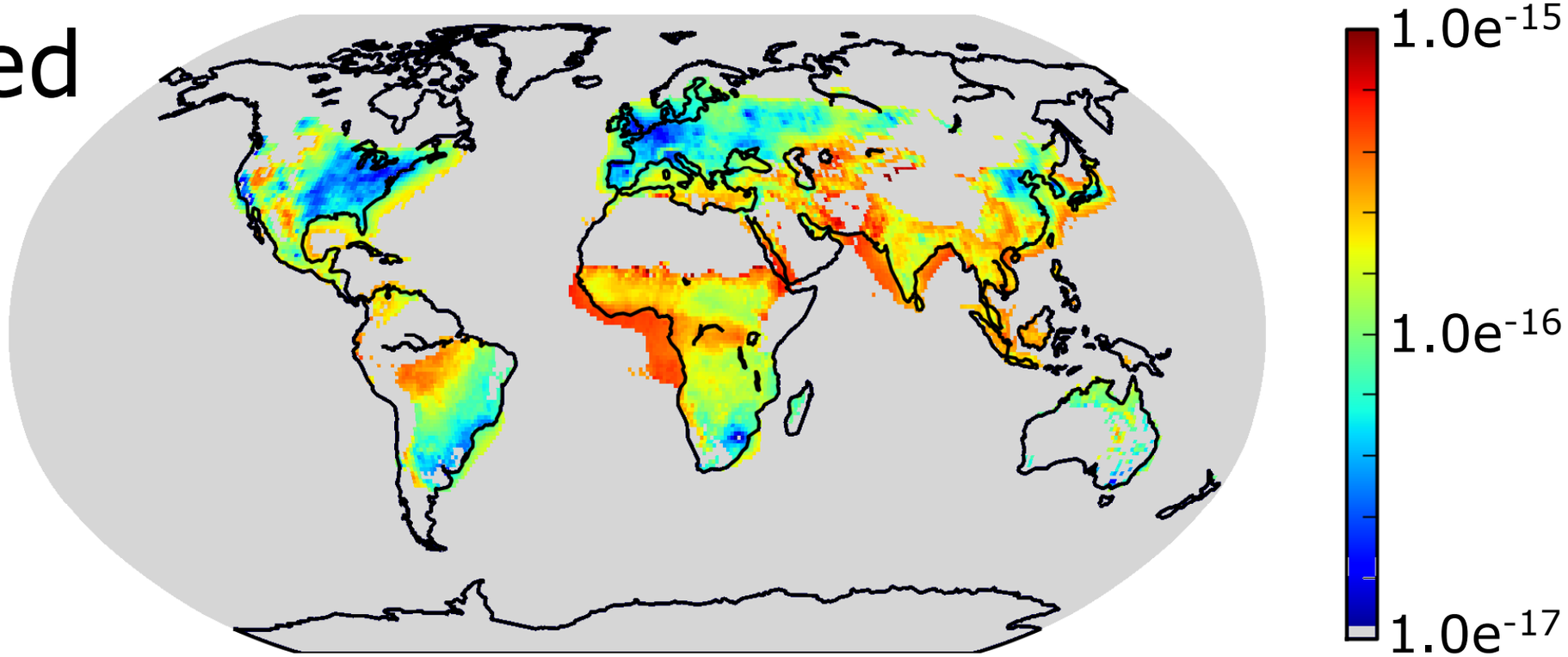
China (Chongqing)



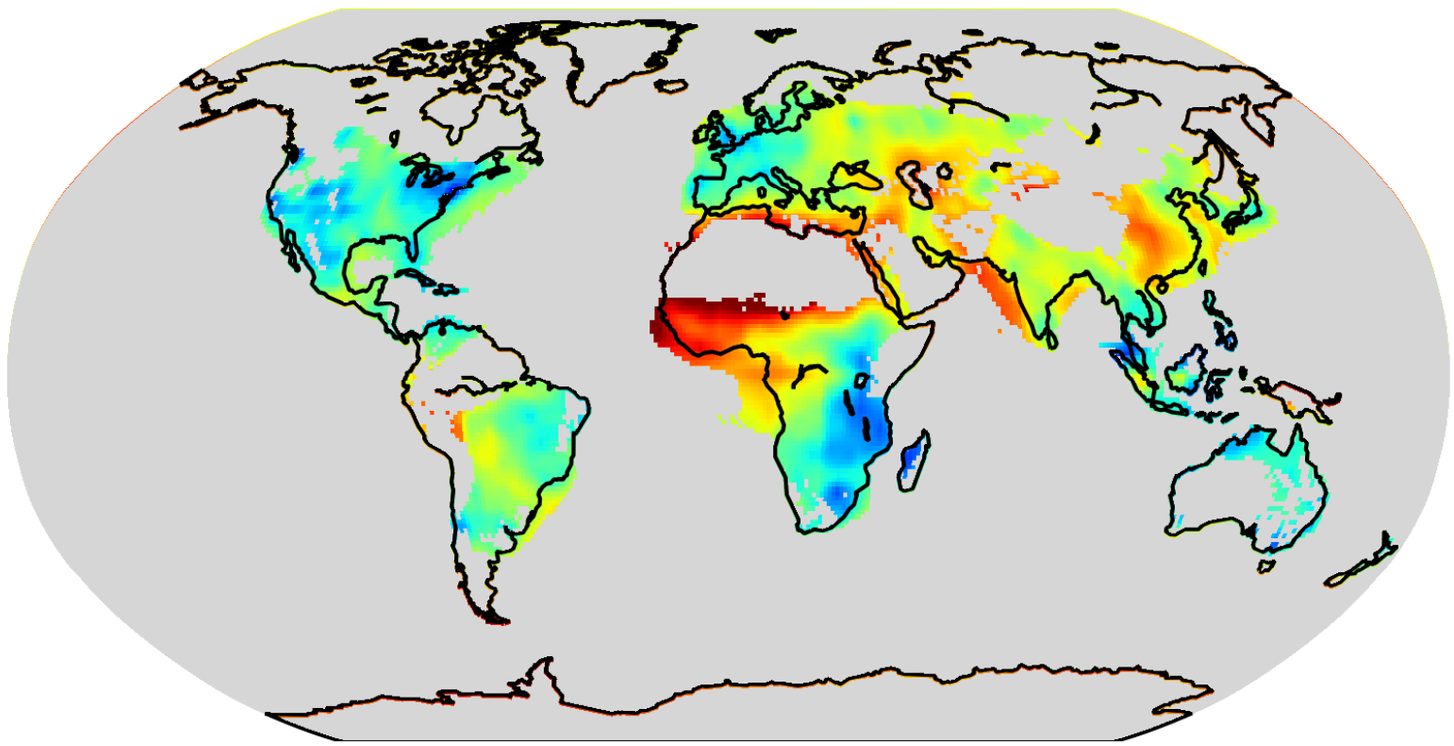
AOT to NO_2 Ratio

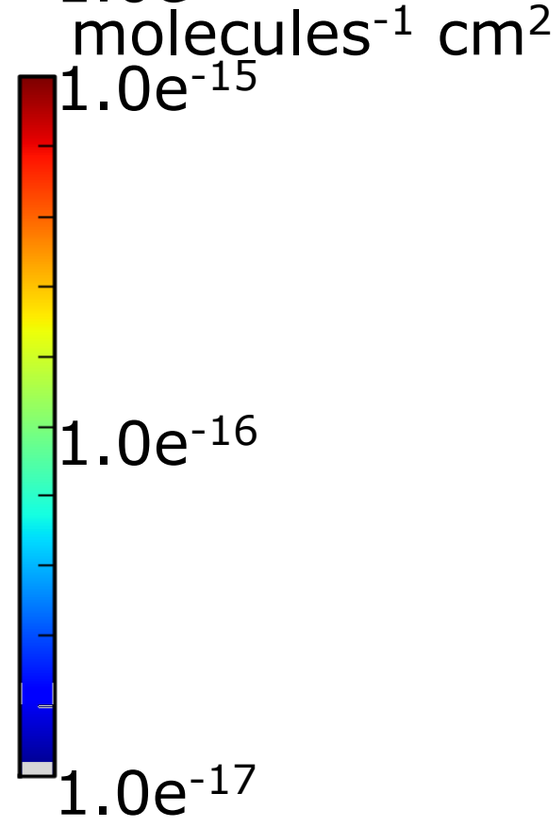
Pollution Control Index

Observed



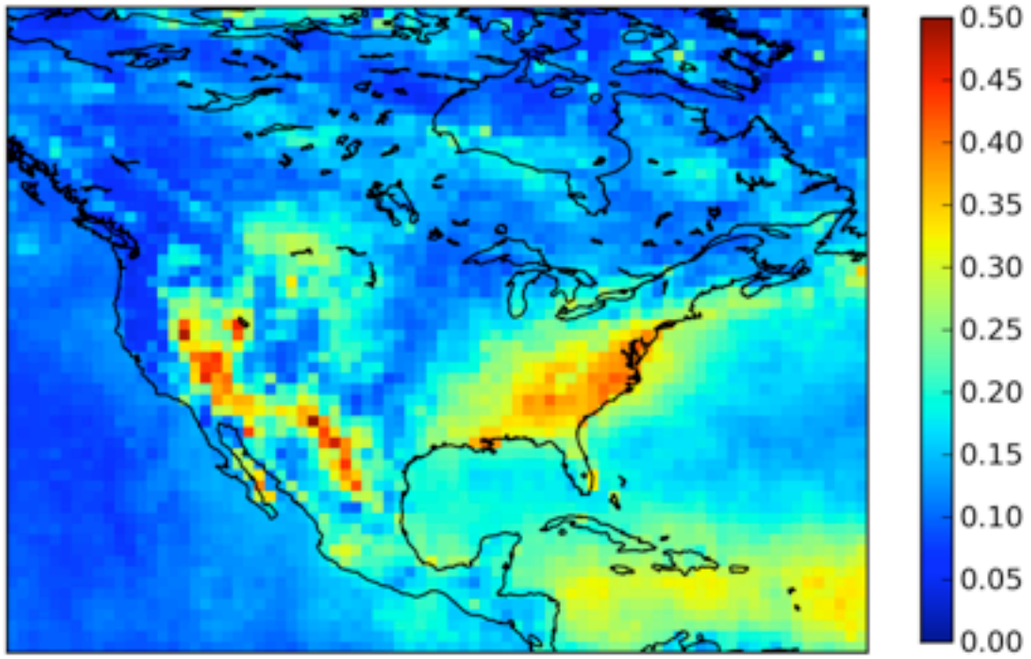
GEOS-CHEM





AOT-HCHO: Summer Anomalies

JJA AOT



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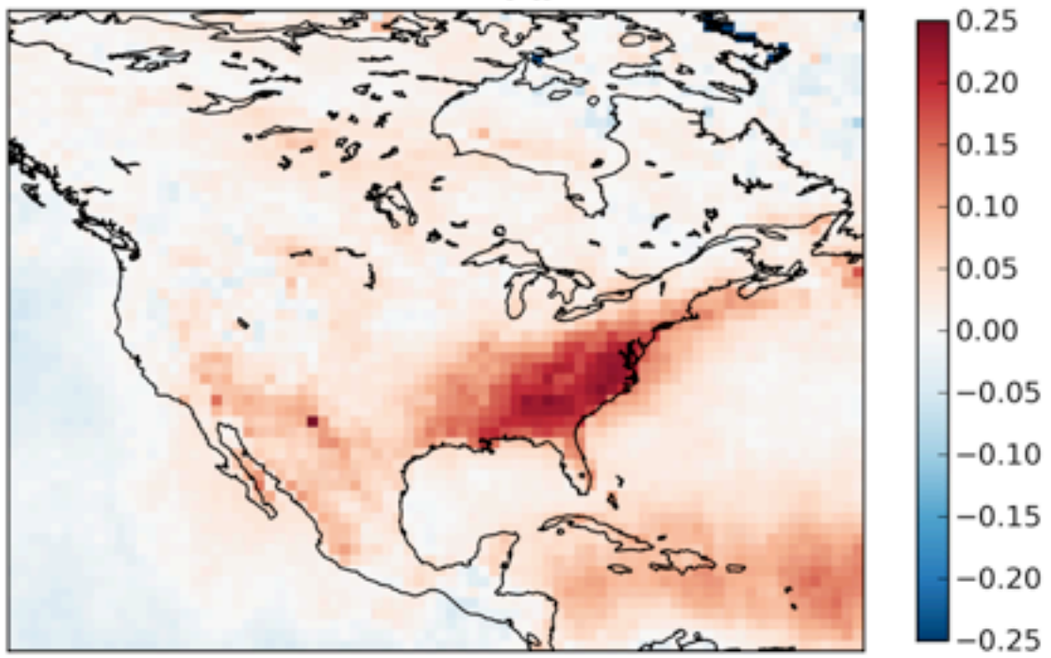
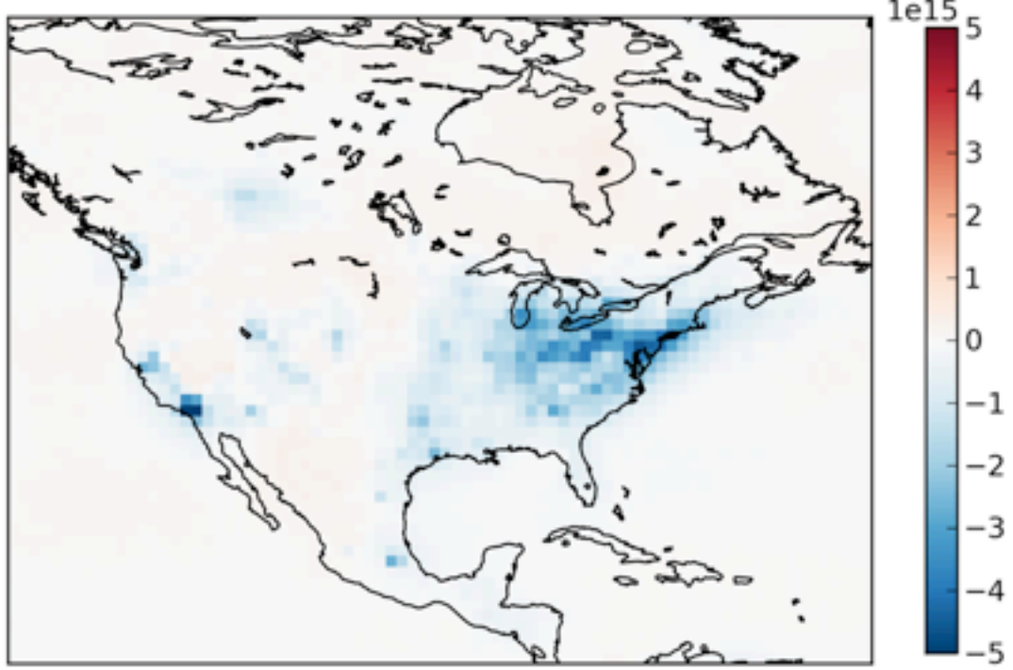


MAM NO_2 Anomaly



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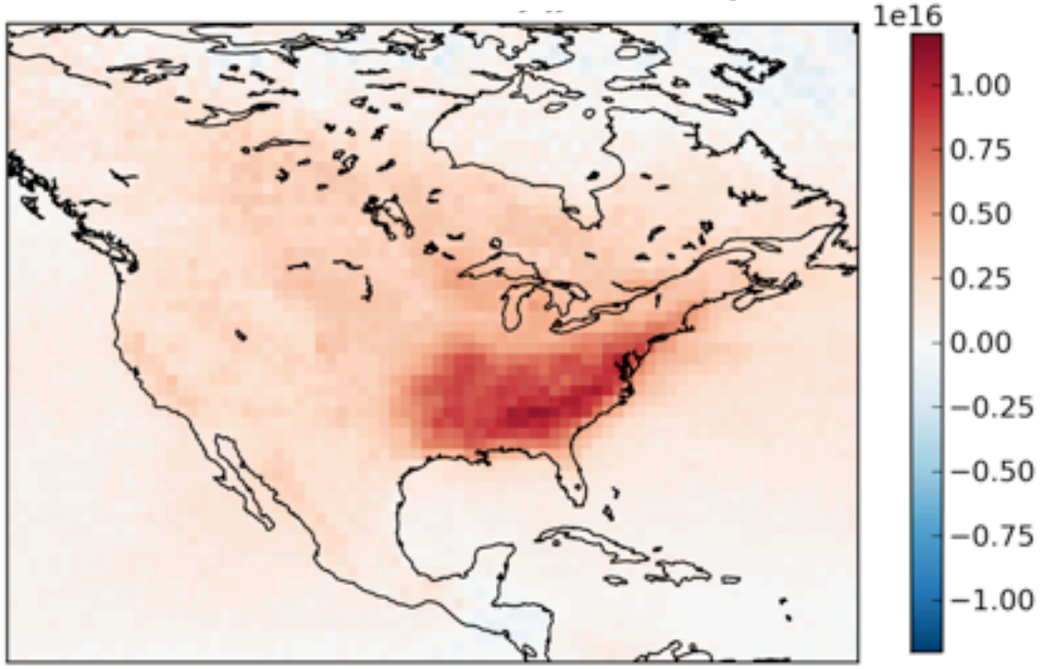
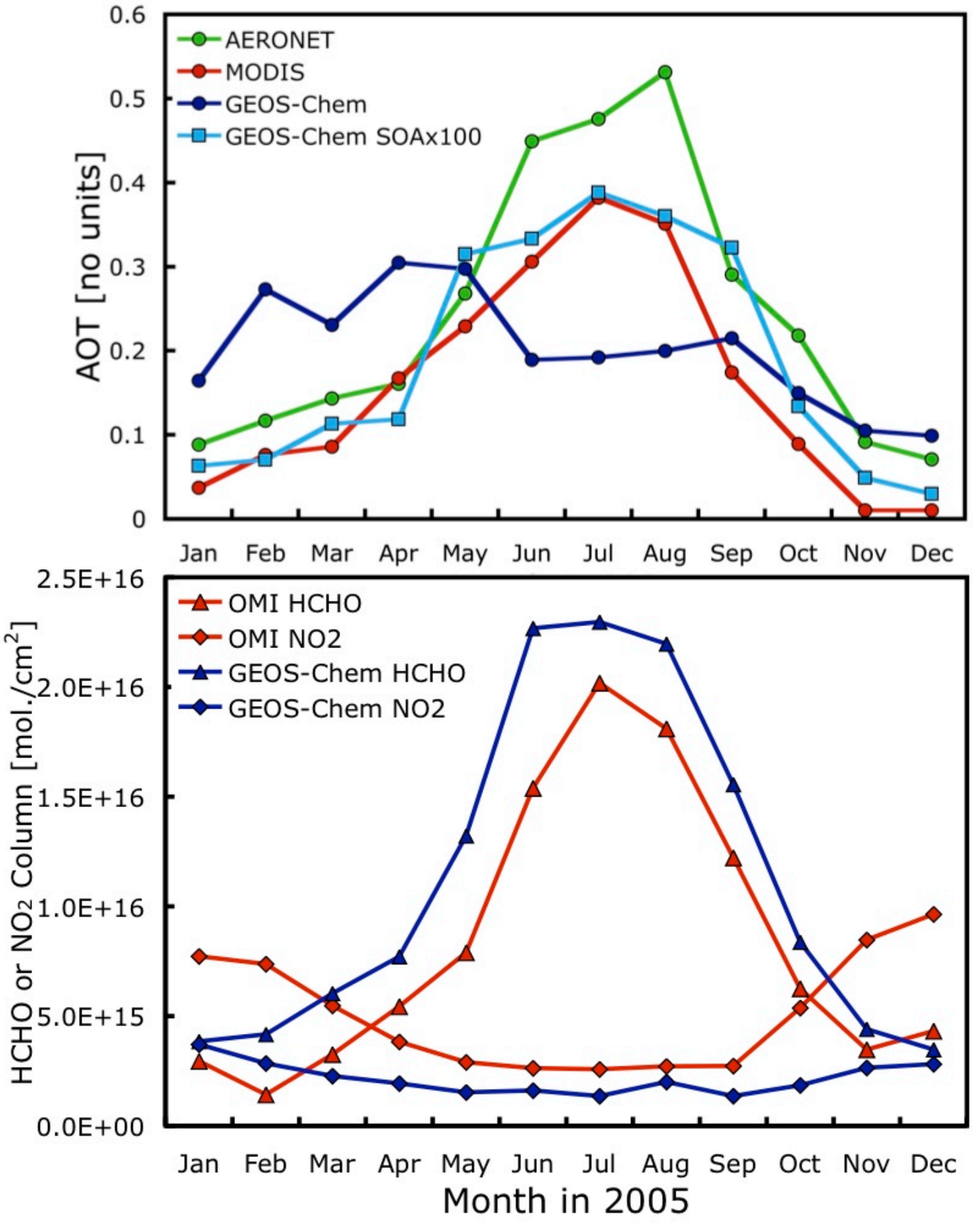


Years 2005-2007

SE USA: Seasonal Variations



- Spatial-temporal correlation between AOT and formaldehyde.
- Formaldehyde is produced from biogenic isoprene sources.
- AOT signal of ~0.2 than models predict. [e.g. *van Donkelaar et al., AE, 2007*]

Conclusions

- For climate assessments it is essential account for the interactions between trace gases, aerosols and clouds.
- The rise to 20 km of the Australian Black Saturday plume can be explained by “self-lifting”.
- This “self-lifting” of absorbing aerosols might have consequences for the residence times of absorbing aerosols and their impact on climate.
- Spatial and temporal correlation between aerosols and their precursors provides indirect information on the aerosol composition and sources.
- The AOT/NO_2 ratio varies strongly globally. This ratio may be used as pollution control indicator.
- Seasonal increases in AOT of the order 0.2, which are spatially correlated with formaldehyde are found in the SE-USA.